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WATER QUALITY BASELINE ASSESSMENT FOR CLEVELAND AREA-LAKE ERIE. VOLUME I. SYNTHESIS

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Cleveland Department of Public Utilities

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Water quality of the near shore waters of Lake Erie in the Cleveland area and of the Cuyahoga, Rocky and Chagrin Rivers was investigated from September 1971 through December 1972 to establish a baseline by which to plan and measure the restorative value of water pollution abatement programs. Seven major investigations by the City of Cleveland and a consortium of 3 universities dealt with fish populations, phytoplankton, zooplankton, benthic organisms, benthic sediment chemistry, water chemistry, cation reactions with the suspended river sediments, and hydrodynamic modeling of river and thermal discharge flow into Lake Erie. Correlation of point sources and of land use with water quality was shown. Changes in game fish populations since the 1950's from predominantly high to predominantly low food value species were clearly demonstrated. An extensive bibliography is included. A framework for management of water quality through system approaches is presented. The study concluded that water quality of the Cleveland-Lake Erie-three rivers watershed area could be restored by implementation of the socio-economic, engineering technological and legal recommendations in the report.

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WATER QUALITY BASELINE ASSESSMENT FOR CLEVELAND AREA - LAKE ERIE
VOLUME I - SYNTHESIS

By

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Prepared by the City of Cleveland
in cooperation with John Carroll University
Cleveland State University, and Case Western
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This report has been reviewed by the U.S. Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does the mention of trade names or commercial products constitute endorsement or recommendation for use.

ABSTRACT

This report presents the results of the first phase of a three phase program in environmental impact assessment, planning and evaluation in urban water pollution abatement for the Cleveland metropolitan area. The first phase investigated the water quality of near shore waters of Lake Erie in the Cleveland area and of the streams in the same area to establish a baseline to measure the progress and restorative value of water pollution abatement programs.

The project was accomplished through a scientific consortium between the City of Cleveland and three area universities - John Carroll, Case Western Reserve, and Cleveland State. Seven major investigations were performed dealing with fish population, phytoplankton, zooplankton and benthic organisms, benthic sediment chemistry, water chemistry, cation reactions with suspended river sediments, and hydrodynamic modeling of river and thermal discharge flow into Lake Erie. Additional work was performed in library research and coordination.

The field investigations were conducted from September of 1971 through December of 1972. The area of investigation included Lake waters from the mouth of Chagrin River along the shore to the mouth of the Rocky River, 35.5 kilometers. The area included the Cleveland Harbor and lower 20 kilometers of the Cuyahoga River.

The study established a rough water quality baseline demonstrating areas of water quality degradation, possible restoration avenues, and need for future research. A gradation from grossly and heavily polluted water zones in the near shore areas to progressively less polluted zones further out into the lake is established based on biological and chemical data. Fish population diversity, distribution and changes are documented. Areas of ecosystem stress are delineated and priorities for ameliorative measures are established. Framework for management of water quality through systems approaches is presented.

Study shows correlation of point sources and water quality depression zones, and biological data indicates that study area waters are undergoing similar degradation as other areas in the Lake Erie Basin. Study also, demonstrates that water quality degradation in the study area started before the industrialization era (circa 1850) resulting initially from alteration of the physical environment. The close tie between land use and water quality shows that other measures besides control of point sources will be required to restore the waters of the area.

This report is submitted in fulfillment of Project Number G005107 under the sponsorship of the Office of Great Lakes Coordinator, Section 108A, U. S. Environmental Protection Agency, Region V, Chicago, Illinois.

CONTENTS

VOLUME I - SYNTHESIS by A. B. Garlauskas

Page

Abstract iii

Figures vi

Tables viii

Acknowledgements xi

ERTS Satellite Photo xiv

Three Rivers Watershed and Vicinity Map xvi

Study Area Map xviii

Sections

I Conclusions 1

II Recommendations 7

III Introduction and Summary 13

IV Methodology of Data Acquisition 51

V Study Results and Discussion 65

VI Needs 119

VII Glossary 131

VIII Bibliography 135

VOLUME II - THE FISHES OF THE GREATER CLEVELAND METROPOLITAN AREA INCLUDING THE LAKE ERIE SHORELINE by Andrew M. White

FIGURES

No.		Page
1.	Three phase program flow and continuity chart	15
2.	Monthly averages of phytoplankton abundances for selected years showing the trend	25
3.	[illegible] of the Cuyahoga River flowing through [illegible]veland	28
	[illegible] ial outfalls on the Cuyahoga [illegible]	32
	[illegible] rge to streams abatement [illegible] rt	35
6.	[illegible] ipitation	36
7.	Infla[illegible]	38
8.	Aerial view of the present Cleveland Easterly Water Pollution Control Plant	39
9.	Aerial view of the present Cleveland Southerly Water Pollution Control Plant	40
10.	Area covered by the study showing sampling stations	43
11.	Total precipitation in the Cleveland area for five years	48
12.	Pollution intensity zones in the near shore Lake area of Cleveland	50
13.	Application of results to Cuyahoga River entering Lake Erie	71
14.	Predicted response of the Cuyahoga River to a Lake current	72
15.	Predicted response of the Cuyahoga River to a current behind the breakwall	73
16.	Typical flow pattern of the Cuyahoga River with the dominant southwest, west, and northwest wind directions	75

17. Cross section of lake water intrusion into the Cuyahoga River from conductivity and dissolved oxygen measurements 76

18. Comparison of sediment and supernatant total N 78

19. Comparison of sediment and supernatant total P 80

20. Sediment composition variation 81

21. Cuyahoga River (mgd) discharge above and below Southerly Waste Treatment Plant in 1972 88

22. The inverse relationship between temperature and dissolved oxygen in the Cuyahoga River 89

23. Street salting impact on the Cuyahoga River 90

24. Concentration and total phosphorus load vs flow in the Cuyahoga River at 11.15 miles upstream from the mouth of the River 92

25. Fecal coliforms vs geometric means monthly average in the effluent of the two wastewater treatment plants on Lake Erie 96

26. Total biomass of phytoplankton for all stations for all months 100

27. Mean total biomass of four different groups of algae for all stations for all months 101

28. Distribution of the major groups of algae 102

29. Relative abundance of the major benthic groups at the fourteen regular sampling stations 105

30. Water quality management interrelationships 121

31. Water quality management functions 123

32. The hierarchical multilevel systems decomposition 126

33. An example of the hierarchical multilevel decision layer structure as applied to a regional phosphorus control program 128

TABLES

No. Page

1. Water quality of Lake Erie and the Cuyahoga River in 1852 19

2. Water quality of Lake Erie in 1865 19

3. Water quality of Lake Erie in 1873-1874 21

4. Water quality of Lake Erie in 1887 21

5. Comparison of changes in water quality reported in commercial fishing reports 23

6. Chloride levels of Lake Erie tributaries in 1904 23

7. Sources and discharges to the Cuyahoga River 27

8. Loads to receiving water from streams 30

9. Pollution loadings from combined sewer overflows 31

10. Sampling stations 44

11. Sampling stations 45

12. Loadings to Lake Erie from Cleveland Harbor and River dredging 68

13. Comparison of Harbor to average near shore sediments 84

14. Comparison of Harbor (filtered) to average supernatant 84

15. Cuyahoga River water quality in 1972 86

16. Performance of Cleveland Wastewater Treatment Plants in meeting discharge criteria for heavy metals during period from February 15 to July 6 of 1972 87

17A. Cleveland Wastewater Treatment Plant pollution loadings in the effluent for 1972 93

18. Number of sampling days of chlorination or non chlorination for 1971 and 1972 95

18A. Species of fishes collected in/or near the Cleveland Harbor 109

19. Average concentrations of sediment constituents 112

20. Viruses possibly present in sewage and resulting diseases 114

21. Plankton analysis of tap water 3200 liter sample taken August 8, 1973 115

22. Regional water quality management programs at Case Western Reserve University 127

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PUBLICATION INFORMATION

All the data obtained on this project is being transcribed into STORET at the time of the writing of this report. The transcription is expected to be completed in the second half of 1974.

This study is presented in two reports. The first report written by A. B. Garlauskas and titled Water Quality Baseline Assessment for Cleveland Area - Lake Erie with subtitle Volume I, Synthesis, summarizes and interprets all information obtained in the study. The second report with the same title subtitled Volume II, The Fishes of the Greater Cleveland Metropolitan Area Including Lake Erie Shoreline is written by Andrew White covering his fish population investigations.

Two of the investigators have published their findings through other entities. These are listed as follows:

Lick, W. and Paul, J.F. A Numerical Model For a Three-Dimensional Variable Density Set. Proc. 16th Conf. Great Lakes Res. 1973.

Rolan, R.G. et. al. Zooplankton Crustacea of the Cleveland Nearshore Area of Lake Erie, 1971-1972. Proc. 16th Conf. Great Lakes Res. 1973.

The other six investigation reports that are summarized and interpreted in Volume I are not planned to be published separately within this study. These unpublished reports are:

Alldridge, N.A. An Investigation of Methods for Making Quantitative

Estimates of Cladophora Growth in Lake Erie.

Alldridge, N.A. Phytoplankton of the Inshore Waters of the Cleveland Metropolitan Area, 1972.

Hower, J., Aronson, J.L., and Kim, H.S. Cation Exchange Reactions Involving Sodium, Potassium, Magnesium and Calcium in Cuyahoga River.

Lick, W. and Prahl, J. River Discharges and Thermal Plumes.

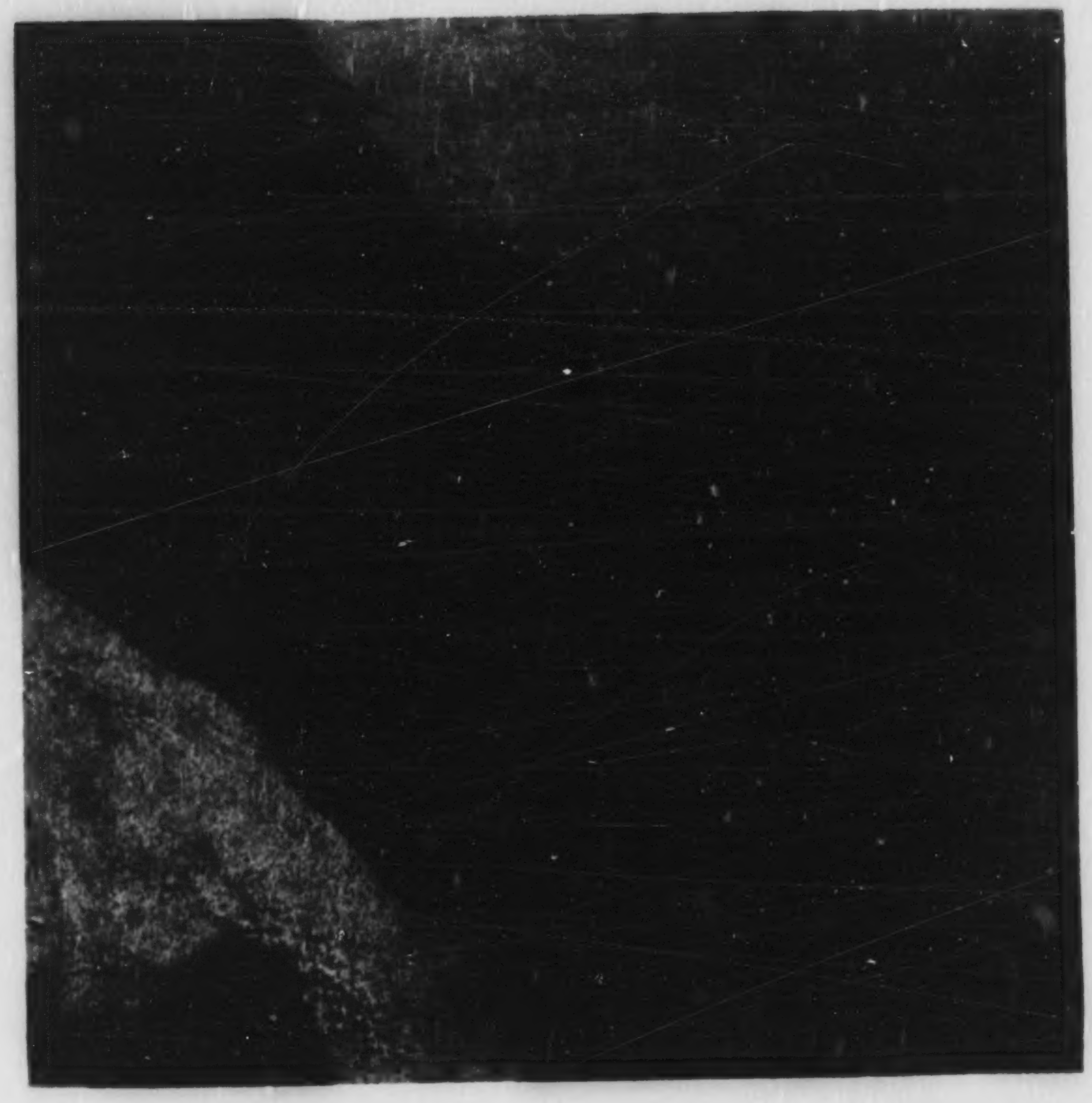
Olynyk, P. Chemical Composition of Sediments of the Cleveland Nearshore Zone of Lake Erie 1971-1972.

Rolan, R.G. Benthos of the Cleveland Near Shore Area, 1971-1972.

The data in these reports will be available from STORET, and the individual investigators are encouraged to publish the reports on their own initiative. All the investigators may be considered as contributing co-authors of Volume I, since portions of their reports are incorporated in the Synthesis.

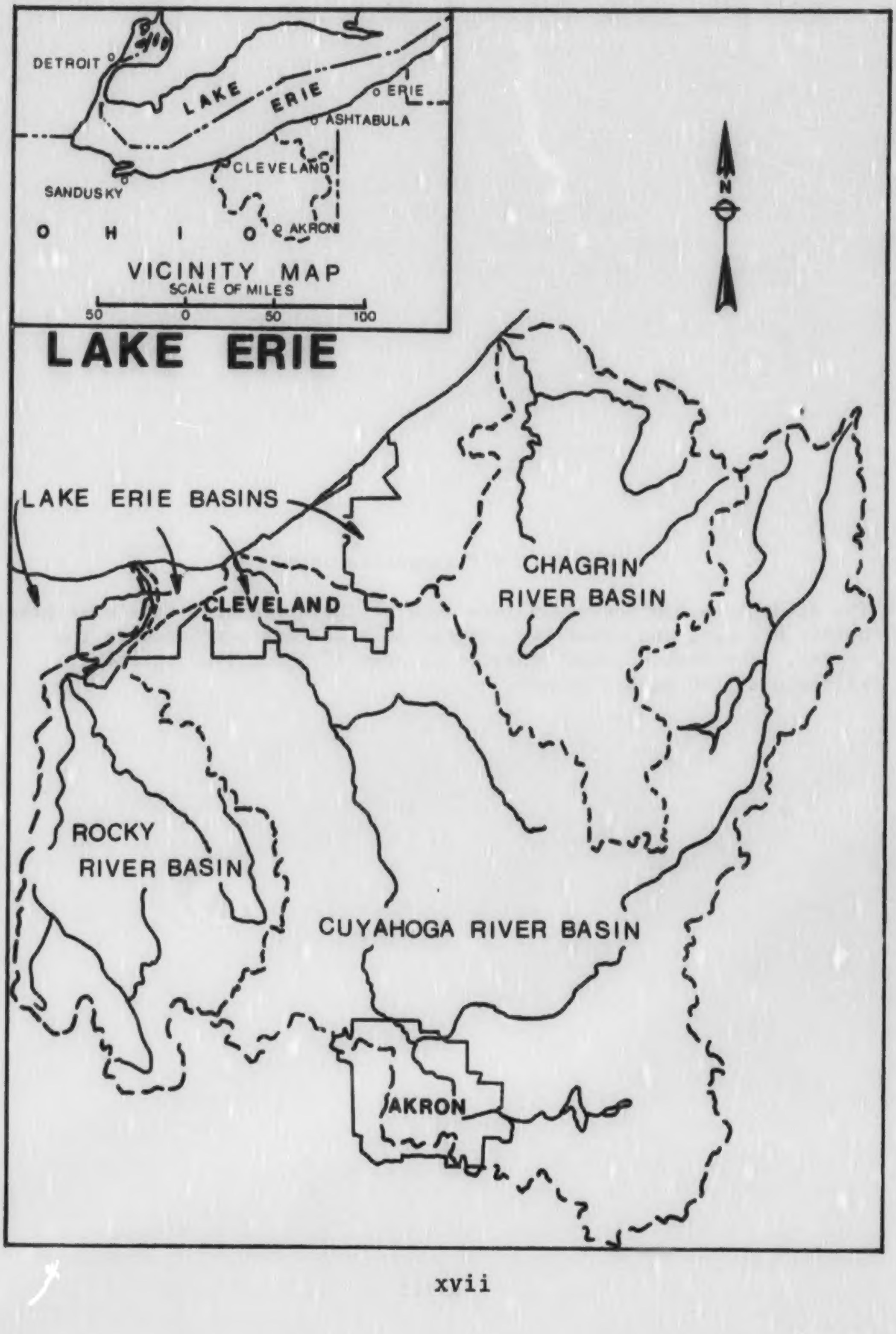
ERTS SATELLITE PHOTO (opposite page)

Lake Erie -- A resource for the millions. Cleveland is below the center of the picture. Remote sensing methods such as this satellite photograph are used in many areas of environmental and resource assessment. One application is in detecting point and area sources, current patterns, and dispersion of thermal and other types of discharges. This technique can be a valuable tool in water quality and resources management. This photo was taken at an altitude of 48 miles on September 4, 1973. (Photo was provided through the courtesy of National Aeronautics and Space Administration)



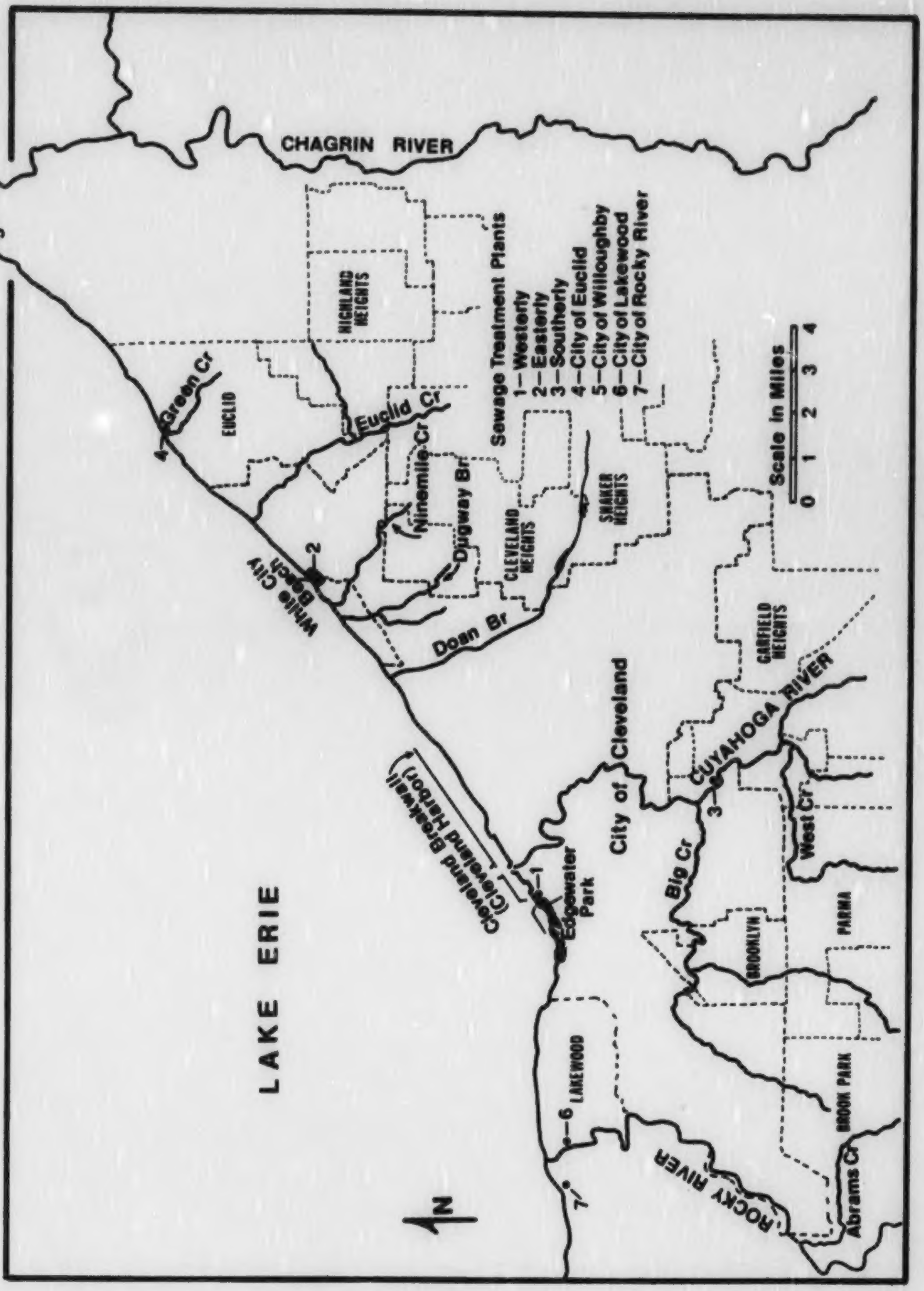
THREE RIVERS WATERSHED AND VICINITY MAP (opposite page)

The Three Rivers Watershed is defined by the drainage basin divides of the three adjoining river basins - Rocky, Cuyahoga, and Chagrin Rivers, which comprise an area of about 2,360 square kilometers (1,474 square miles).


DETROIT
LAKE ERIE
ERIE
ASHTABULA
CLEVELAND
SANDUSKY
O H I O
AKRON
VICINITY MAP
SCALE OF MILES
50
0
50
100
N
LAKE ERIE
LAKE ERIE BASINS
CLEVELAND
CHAGRIN RIVER BASIN
ROCKY RIVER BASIN
CUYAHOGA RIVER BASIN
AKRON

STUDY AREA MAP (opposite page)

The study area map shows the locations of the wastewater treatment plants, public beaches, and other key geographic locations mentioned in the report. The area of study covered an area of about 1400 square kilometers (840 square miles).


LAKE ERIE
N
CHAGRIN RIVER
CUYAHOGA RIVER
ROCKY RIVER
Sewage Treatment Plants
1—Westerly
2—Easterly
3—Southerly
4—City of Euclid
5—City of Willoughby
6—City of Lakewood
7—City of Rocky River
Scale in Miles
0
1
2
3
4
HIGHLAND HEIGHTS
EUCLID
Green Cr
Euclid Cr
Ninemile Cr
Dugway Br
CLEVELAND HEIGHTS
SHAKER HEIGHTS
White City Beach
Doan Br
GARFIELD HEIGHTS
City of Cleveland
Cleveland Breakwall (Cleveland Harbor)
Edgewater Park
Big Cr
West Cr
BROOKLYN
PARMA
LAKEWOOD
BROOK PARK
Abrams Cr
1
2
3
4
5
6
7

SECTION I

CONCLUSIONS

The conclusions derived from this study fall into two broad categories. One category is made up of conclusions that are derived from the general synthesis of all the individual investigations and the total project. The other category presents conclusions as derived in individual investigations

I. The general conclusions are:

1. The water quality in the study area is heavily degraded. The streams are filled with debris, sewage, and in places with industrial waste. The near shore waters of Lake Erie are heavily polluted with industrial and sewage wastes.

2. The near shore waters of Lake Erie in the study area are variable in water quality showing pollution zones which have been correlated to point sources.

3. The most pronounced zone of degraded water quality is at Edgewater Park and the Cleveland Harbor. The Edgewater Park water is degraded by the inadequately treated municipal discharges of the Westerly Sewage Treatment Plant; whereas the harbor is degraded from at least four sources -- the Cuyahoga River, river dredgings, leaching from old fills and septic tanks, and storm sewer discharges.

4. The dilution effects on discharges and general pollutant concentrations distorted the data obtained on the project. The dilution resulted from greater volumes of available receiving waters from increased precipitation in 1972 and higher lake levels.

5. Factors like denudation of land, damming of streams, and draining of marshes were the initial steps that led to the degradation of water quality in the region.

6. Based on all the data obtained, the near shore waters in the study area are enriched and are eutrophic, with intermediately polluted zones occurring along the shore east of the Cleveland Harbor.

7. The project reevaluated and concluded that the 1968 Havens and Emerson MASTER PLAN FOR POLLUTION ABATEMENT can still be an important part of a viable base for continued water quality restoration efforts in the Cleveland area.

8. A historical review of the water quality indicates degradation occurred before 1850, and the dissolved solids began to increase at about the same time. This implies that the present Lake Erie restoration goals and water quality standards must reevaluate the

general premise of using 1900 conditions as the restoration level baseline.

9. Specific sociological and economic data is not available to help evaluate water pollution abatement progress, and therefore studies to obtain such data must be undertaken.

II. Conclusions derived from individual investigations are:

1. The Cuyahoga River appears to be heavily polluted before it reaches Cleveland, and in terms of the cations studied - calcium, sodium, potassium, magnesium, - their addition in the Cleveland portion of the river cannot be quantified by buffering reactions of the suspended sediment. The buffering capacity of the suspended sediment is nearly exhausted by reactions in the stream above the Cleveland area due to upstream pollution. The buffering reactions involve bottom sediments.

2. No pronounced differences in chemical composition of the near shore waters was found as related to the 1968 Lake Erie Report of the Federal Water Pollution Control Administration.

3. A pronounced water quality depression effect was established caused by the Southerly Wastewater Treatment Plant discharges on the Cuyahoga River. This depression is characterized by addition of nutrients, suspended solids, and bacteria.

4. The Cuyahoga River exhibits a seasonally related and temperature-flow dependent sinusoidal fluctuation of dissolved oxygen.

5. The fish fauna of the Cleveland-Lake Erie shoreline is, at present, markedly different than in former times. The species composition has changed from one of highly valuable food species and clean water forms (i.e. Muskellunge, Walleye, Lake Trout, Silver Chub, Burbot), to one of a predominance of rough fish and low food value species such as the Goldfish, Carp, Gizzardshad and Perch. The dominant species have changed from large piscivorous species to primarily plankton and bottom feeding species such as the Gizzardshad and Carp.

6. The fish populations of the Cleveland metropolitan area are under stress from the degradation of the ecosystem and that the stress varies significantly within the study area. The most highly distressed area is the lower seven miles of the Cuyahoga River and the least distressed area is the middle and upper portions of the Chagrin River drainage. Other areas display various degrees of degradation.

7. In the entire study area, including the lower Cuyahoga River, there were no areas found where a fish fauna was completely absent. While the fauna of the most distressed reaches of the Cuyahoga River is meager, consisting of only occasional individuals of only a

few species, it is concluded that fishes routinely enter the lower reaches of this stream from the Cleveland Harbor. The fishes are almost exclusively pollution tolerant "rough" fishes, primarily goldfish.

8. The most recent period of game fish decline in Lake Erie occurred in the 1950's when the Blue Pike (Walleye), the Yellow Walleye, the Burbot and many others suffered a sudden and drastic reduction in numbers. While the Yellow Walleye appears to have made a partial recovery in other portions of Lake Erie, its numbers in the Cleveland area remain critically low, primarily due to pollution loadings from sewage and other discharges. The Blue Walleye is considered by many to be extinct.

9. Literature, museum and present survey records indicated that a total of 105 species and subspecies of fishes have at one time inhabited the study area. Presently, our survey indicates that 46 (44%) of these are either rare or probably extirpated within the study area. Of the 105 species, we have documented the presence of 84 within the area and it is probable that several more exist in very small numbers.

10. The Cleveland area can be restored to its former position as a viable fishery, although it is obvious that certain species will be very difficult if not impossible to restore. Should the conditions along the shoreline and in the rivers improve, we are of the opinion that most of the species would recover quickly.

11. The principal areas which must be restored are those which formerly served as major spawning areas. The area which apparently served as the most important area of fish reproduction is the lower Cuyahoga River and the adjacent shoreline.

12. The principal cause of the decline of fish populations in the area was the destruction of spawning areas and the elimination of access to such areas by the activities of man in the study areas. The sport or commercial removal of fishes played a minimal part in the reduction of the area fish fauna.

13. Those species which spawn in the offshore, deeper portions of Lake Erie have shown the least reductions in number, indeed many of these have increased greatly in number. Successful reproduction of at least 12 species of fishes has been documented within the Cleveland Harbor and the adjacent marinas. A single species, the Goldfish, is probably reproducing in the lower five miles of the Cuyahoga River. Records show that a number of different game fishes used to reproduce in the River, such as perch, trout, etc.

14. The major nursery zones along the Lake Erie shoreline are (in order of decreasing production), the Cleveland Breakwall and adjacent marinas, the lower Chagrin River, the lower Rocky River,

the Lake Erie shoreline, the lower Cuyahoga River. The Chagrin has a greater variety of species.

15. Major areas of fish concentrations appear to be correlated with either the presence of a pollution source or the presence of protected waters such as marinas, harbors, or river mouths. This is to be expected and has been documented in other studies.

16. The principal areas of sports fishing are associated with the preceding areas of pollution input or structures.

17. The species of fishes which have most severely declined are those which spawned in the upper sections of the river drainages, entering each spring from Lake Erie to spawn. The former spawning areas of these fishes have either been drained, silted, or blocked by the construction of dams. Those species of fishes which formerly spawned in the lower river mouths or on the gravel bars and beaches along the shoreline have also declined sharply since 1850.

18. The decline and change in the fishery both in Lake Erie and in the rivers did not primarily occur in the past few years. The first major decline in the fishery occurred prior to 1850 and included the nearly complete collapse of the local populations of Muskellunge, Northern Pike and other stream spawning species. These species have not recovered since that time.

19. The species diversity and relative abundance of fishes changes seasonally along the Cleveland shoreline due to the seasonal use of the area by various species. The diversity is highest in the late spring, and is lowest in the late summer (July-August). The diversity and relative abundance of fishes changes on a more regular basis in the lower rivers and may change greatly from day to day, or day to night.

20. In general, the diversity and abundance of fishes along the shoreline does not vary during a given season. This indicates that little or no avoidance of selected areas occurs with those species which are highly pelagic.

21. In general the species diversity index and the species composition along the Cleveland shoreline is low, probably reflecting the great preponderance of the Yellow Perch. Our collections on the beaches and in the shallow areas of the shoreline (one to two feet deep) indicate a trend toward cleaner and more diverse types of fishes both to the east and west of the City of Cleveland, with a very diverse and abundant fauna in the vicinity of the beaches at the Chagrin River mouth.

22. Proposals and early action is essential to the reversal of the declining fishery in the area. The early reversal of the degradation of the shoreline and lower rivers is essential to

restore those spawning areas which have been destroyed.

23. The Chagrin River system should be protected by all agencies, Federal, State and Local. This is essential since the primary source of repopulation stocks of fishes is this river drainage.

24. The highest average phytoplankton biomass occurred during September. At no time did the blue-green algae constitute a major portion of the biomass. The highest computed proportion was 20% of the total. During the summer months the green algae accounted for the greatest proportion of biomass, with the single dinoflaggelate genera, Ceratium being second. During the winter months, the diatoms comprised the major portion of the biomass.

25. Zooplankton crustacean communities, especially the Copepoda and Cladocera components, have increased in abundance since the early 1950's. This increase suggests that the Cleveland lake front area is undergoing changes similar to those of the Lake Erie western basin due to eutrophication. This study did not clearly delineate benthic seasonal trends, except for a general population decline in June, 1972, due in part to the emergence of chironomid larvae as adult midges. The benthos indicates that the Cleveland lake front ranges from grossly polluted to eutrophied areas.

26. The benthic sediments are highly polluted containing toxic metals and nutrients characterized by phosphorus and nitrogen compounds. Comparisons with data from other reports show that phosphorus is accumulating in the near shore sediments.

SECTION II

RECOMMENDATIONS

All the recommendations are based on the premise that the Program (Figure 1) will continue with Phase II. The recommendations are presented in the interdisciplinary network shown by the "Environmental Management of Water Quality" diagram (Figure 30). Only high priority areas are covered by recommendations which are given by category.

ENVIRONMENT

In obtaining additional vital information on the natural environment these recommendations must be implemented:

1. Derive a quantitative balance of the hydrologic cycle (water budget) of the area through the watershed approach, which includes stream hydrology (flood stage, low flow, hydrographic analysis), micro-precipitation patterns, total hydrogeology, including groundwater table, infiltration, recharge, discharge areas, runoff, etc.

2. Determine the near shore lake currents, and physical characteristics of the lake influence of the Cuyahoga River, which can be classed as an estuary.

3. Develop a physical inventory of the region, including the surficial geology and topography and pinpoint areas of instability, erosional potential, and natural sedimentation patterns.

4. Develop a detailed viable clean water index, incorporating chemical, biological, and physical parameters. It must be usable for continuous monitoring of water quality in this geological region.

DISRUPTIONS

In the area of environmental disruptions these recommendations must be implemented:

1. Develop a comprehensive mass balance of point source pollution loadings, integrated with area sources and total receiving and discharge loadings. This mass balance should be compared to natural pollution loadings and total water budget. Atmospheric washout of air pollutants must be included.

2. Develop a pollutant profile to map the dispersion pattern of the Cuyahoga River discharge into Lake Erie, including data on pollutant types, concentrations in the sediments, thicknesses of sediments coordinating this profile with deposition and erosion patterns.

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3. Assess previously used open lake dredge dumping sites ecologically as to the regenerative ability of such areas. This would be valuable information in the consideration of open lake dumping as an alternative once the ten year ban by the Environmental Protection Agency on open lake dumping expires.

4. Determine effects of discharges from filtration plants. Materials like aluminum hydroxide, activated carbon and backflushing matter from the area filtration plants are discharged into streams and ultimately the lake. The rationale is that the aluminum hydroxide and carbon are not very harmful and that the backflushing material came from the lake originally.

5. Minimize impacts of dredging in the marinas and harbor on spawning areas as shown by the fish population study.

6. Develop a computerized comprehensive instantaneous readout water quality monitoring system to provide immediate information on request of possible health hazards and pollution loadings near public water supply intakes.

7. Develop, based on quantity and impact, a classification of environmental disruptions related to water quality in the area including the mode, the scale, and relative rank.

8. Develop and begin an integrated, consistent monitoring network of water quality in the area waters.

EFFECTS

In the area of effects the major recommendations that must be acted on are:

1. Develop and implement research and testing on biological and chemical hazards in the waters of the lake near shore area and streams to determine possible paths and effects on public health. This must include testing for viruses, and toxins from algae in the public water supply; determine mobilization of heavy metals in the aquatic food chain where the top consumer is man, especially as related to fishes caught in the Cleveland waters.

2. Develop a detailed historical reconstruction of the ecology of the area relating the changes to pollution and other environmental disruptions caused by human activities.

3. Determine the economic impact of water quality degradation in the Cleveland area. This must include increased cost of water treatment, loss in commercial fish, direct damage to property, loss of aesthetic and recreational aspects, etc.

(HUMAN) ECOSYSTEM

In the socio-political areas, these recommendations must be implemented:

1. Determine through surveys public awareness of water quality problems in the Cleveland area; determine the relationship of environmental values to socio-economic conditions, cultural patterns, and geographic location.

2. Establish within the area an Institute for Environmental Studies which would be composed of industrial and civic leaders, government and area university top representatives. This institute would serve to define problems of environmental concern, design objectives, develop programs for consideration, involve the public in program planning, approval, and implementation.

3. Conduct a survey in all phases of human activity in the area to determine the extent and effectiveness of the blending of the social and physical sciences as related to environmental problems; and determine also the interdisciplinary exchange especially as related to area educational programs in environmental areas.

ENGINEERING AND TECHNOLOGY

In this area the recommendations must be implemented in several projects. These are:

1. Determine the impact and restoration value of the new Westerly physico-chemical treatment plant effluent on the Old Cuyahoga River Bed. Since this new plant will be the largest of its type in the world, this evaluation must include determination of baseline conditions - site geology, hydrology, and ecology. This project should provide for monitoring the Edgewater Beach and west end harbor area.

2. Determine engineering and economic feasibility of converting all wastewater treatment plant and water filtration plant disinfection facilities from chlorination to ozonation, this being a more effective and no residual type method.

3. Develop methods of inactivating bottom sediment chemicals in the lake to prevent their release into the aquatic environment. This would involve the study of the dynamics of various elements (phosphorous, etc.) in the area, and inactivation techniques through use of natural materials such as clays.

4. Develop feasibility of establishing breeding areas for stream spawning fish in the old riverbed of the Cuyahoga River. The extremely high quality of water from the proposed Westerly physical-chemical treatment plant plus aeration could provide an excellent environment for fish populations.

5. Develop methods for increasing fish populations around the Cleveland area by improvements in feeding and breeding zones. One method which has had success in salt water use is the construction of artificial reefs. Large objects of clean debris and tires can provide suitable habitats for fish populations.

6. Develop procedures, both technical and sociological for utilizing materials removed from river and stream channels to transform poor land to productive land within the boundaries of the Three Rivers Watershed area. This should include finding of final use for effluent from wastewater treatment plants.

7. Develop better dredge material disposal methodology. Deep well disposal of dewatered dredge materials into worked out sections of the International Salt mine should be investigated. Preliminary investigation indicates this may be a feasible long term solution to a serious pollution problem.

8. Develop an interdisciplinary model for the restoration of a polluted urban watershed based on a real small watershed, and carry through on the restoration.

9. Develop and carry through a comprehensive restoration program of desirable food fishing commerce. Based on fish population studies, there is evidence that a number of more desirable food fish species can repopulate the area waters.

ENFORCEMENT

In this area of legal controls the recommendations must be implemented:

1. Develop guidelines for land use adjacent to streams and subsequent stream use which can be incorporated into a set of regulations applicable to the Cleveland and Three Rivers Watershed area.

2. Adopt Ohio State water quality laws for enforcement at local and regional levels through the City of Cleveland and Cleveland Regional Sewer District water quality and pollution control administrative components.

3. Develop the legal framework to establish a Regional Water Quality Authority based on the Three Rivers Watershed area. This regional authority should have control over public water supply, waste treatment facilities, all natural waters in the area, and land use.

4. Develop a legal framework to manage the Lake Erie shoreline. The shoreline, being a dynamic interface between lake and land, must be allocated for non-intensive uses, primarily recreation. The areas where erosion is severe, must be acquired by government

and opened for non-intensive parkland development.

5. Design specific laws and procedures to minimize soil erosion from exposed areas during construction and development, and from areas that are not properly maintained.

6. Institute immediate legal provision to protect the Chagrin River, which is the prime breeding area of fish in the Three Rivers Watershed.

7. Assign all the legal responsibility and authority to coordinate and wherever possible carry out all the recommendations in this report to the Water Quality Program, City of Cleveland.

SECTION III

INTRODUCTION AND SUMMARY

BASIC GOALS AND OBJECTIVES OF THE PROJECT

This study was initiated as the first phase of a three phase program in response to the critical need to develop increased capability in predicting the environmental impact of pollution abatement projects in the Cleveland area. Apart from this three phase program, no other comprehensive environmental impact assessment programs are planned or incorporated as part of the water pollution abatement efforts in the Cleveland area. As a consequence, unless this three phase assessment program is carried through as planned, with appropriate and timely modifications, present and future water pollution control programs will have no basis for assessment of degree of success and impact in relation to water quality.

The three phase program is designed to provide sound scientific water quality assessment techniques and methodology within a dynamic, continuous, water pollution control program in the Cleveland area as developed by U. S. Environmental Protection Agency, and followed through by Ohio Environmental Protection Agency, the Cleveland Regional Sewer District, and the City of Cleveland. Geared toward predicting the environmental impact of water pollution abatement programs in the heavily degraded waters of the Cleveland area, this program can serve as a planning model for other urban areas experiencing similar combined industrial, municipal, and urban runoff wastewater loadings to their watersheds.

The general objective to develop an environmental impact assessment capability was derived from the basic goal of aiding in the water pollution abatement effort in the Cleveland area. Five major specific objectives were designed to be achieved over the course of the three phase program:

1. Assess the impact of an urban water pollution control program on the aquatic environment and determine its cost-effectiveness in reducing pollutional stresses. Major effort will center on the evaluation of the environmental impact of a physical-chemical Advanced Wastewater Treatment Plant, handling a combined load of municipal, industrial, and urban runoff wastes.

2. Develop methodology for interfacing water quality assessments and criteria with continued water pollution control planning (such as the modification of specific unit treatment processes).

3. Develop recommendations for demonstration programs in urban water pollution control.

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4. Develop necessary methodology for assessing changes in the aquatic environment as a result of the abatement program, including the possibility of recommending specific water quality criteria for restoring and protecting the waters of Lake Erie with emphasis on the near shore area.

5. Observe, document, and evaluate the restoration value of the Cleveland program.

These specific objectives are to be achieved through a program designed in three overlapping phases (See Figure 1.):

Phase I
The first phase was designed to prepare and execute a baseline study to evaluate the present pollution load and water quality conditions in the Greater Cleveland Lake Erie shoreline area. Insofar as possible, a preliminary assessment of the pollution load impact was also sought.

Phase II
The second phase deals with a detailed assessment of the Cleveland area water pollution control abatement impact. This phase is a long term segment of the entire program. Included in this phase are:

1. Development of a predictive capability to assist in planning water pollution control for specific environmental impacts.

2. Development of necessary assessment methodology such that cost-effectiveness of control programs can be measured.

3. Development and implementation of an effective interface between environmental impact assessment and planning-operations efforts.

Phase III
The third phase will provide the evaluation of cost-effectiveness for the entire water pollution abatement efforts in terms of its restorative environmental impact. This phase would provide upon termination a water quality monitoring basis as part of ongoing water resources and water pollution control planning and management in the Cleveland area.

The three phases, as shown in Figure 1., are part of a comprehensive environmental impact assessment, planning and evaluation program in urban water pollution abatement, with the termination of one phase overlapping over the initiation of the following phase.

The first phase of the program was carried out by the City of Cleveland during 1971 and 1972 under a grant from United States Environmental Protection Agency. Baseline information was gathered by City of Cleveland scientists and specialists from a consortium of three universities--Cleveland State, John Carroll, and Case Western Reserve under subcontract from the City.

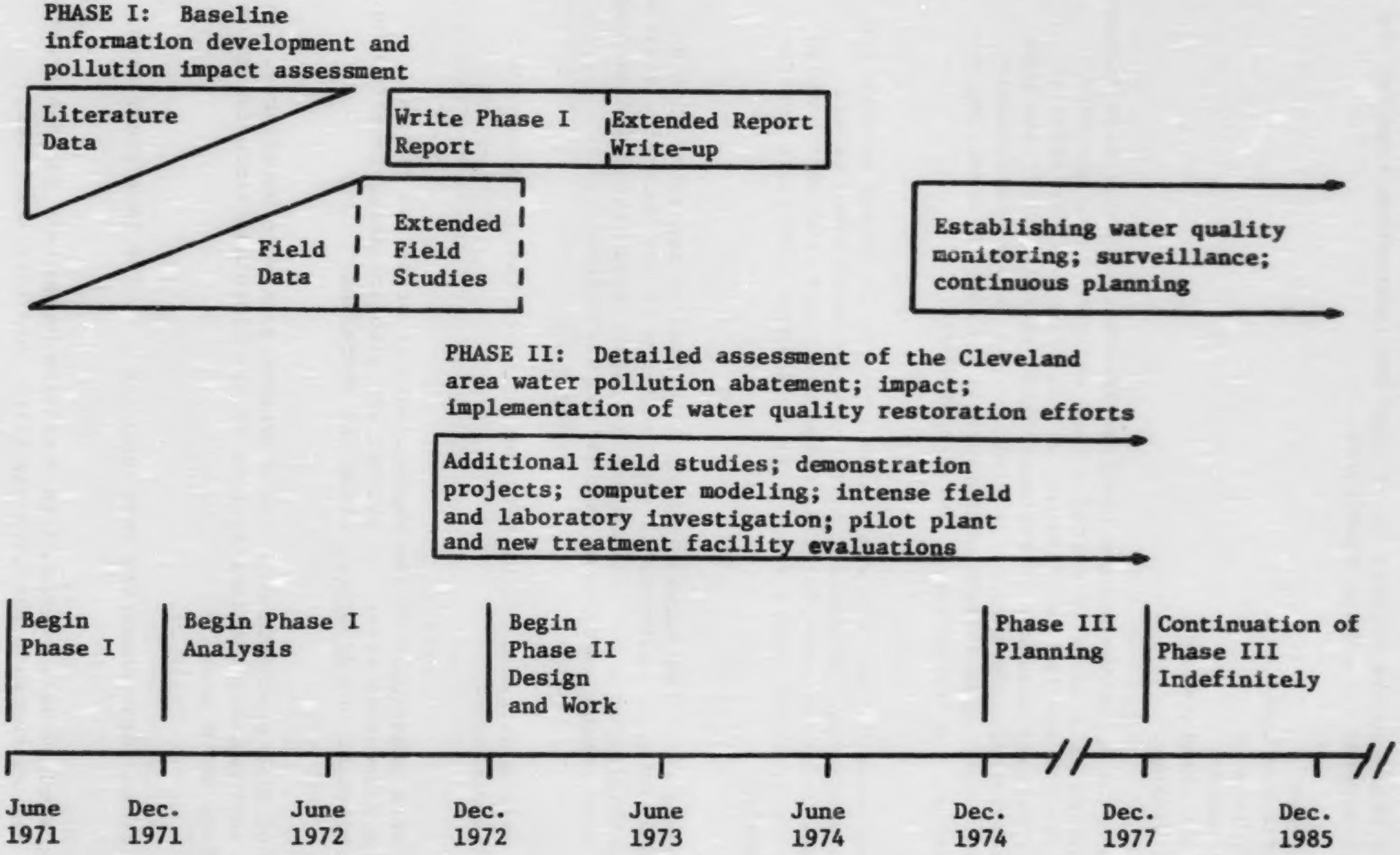

PHASE I: Baseline information development and pollution impact assessment
Literature Data
Field Data
Extended Field Studies
Write Phase I Report
Extended Report Write-up
Establishing water quality monitoring; surveillance; continuous planning
PHASE II: Detailed assessment of the Cleveland area water pollution abatement; impact; implementation of water quality restoration efforts
Additional field studies; demonstration projects; computer modeling; intense field and laboratory investigation; pilot plant and new treatment facility evaluations
Begin Phase I
Begin Phase I Analysis
Begin Phase II Design and Work
Phase III Planning
Continuation of Phase III Indefinitely
June 1971
Dec. 1971
June 1972
Dec. 1972
June 1973
June 1974
Dec. 1974
Dec. 1977
Dec. 1985

Figure 1. Three phase program flow and continuity chart

The first phase in the collection of baseline information required the skills of several scientific disciplines:

limnology
aquatic ecology
hydrodynamics
geochemistry
aquatic chemistry
fish biology

Although a broad, comprehensive baseline information collection framework was attempted, the areas of specific task assignments to the subcontractors for specialized information gathering were relatively narrow. The City assumed the responsibility to fill in all the gaps and synthesize all the specialized information into a comprehensive framework. Each area of information requiring special expertise was designated as a specific task. These tasks were:

Task 1
Pollution input to the lake study area from the Cleveland metropolitan area was monitored. Monitoring stations were established on all continuous point sources of loads to the study area and were sampled weekly. In addition, waste input data from other literature sources were compiled.

Task 2
Ion exchange reactions between suspended particles and water in the Cuyahoga River were examined. A determination of the buffering actions of the particles on major cations was a primary objective. The cations studied were sodium, potassium, magnesium, and calcium.

Task 3
Surveys were undertaken of the zooplanktonic and benthic organisms in the near-shore area.

Task 4
Surveys were undertaken of the phytoplanktonic organisms of the Cleveland near-shore area. An attempt was also initiated to determine the distribution of Cladophora along the shoreline.

Task 5
Surveys of fish populations in the Cleveland area were undertaken. These surveys included major stream systems in the Cleveland vicinity, as well as the lake study area.

Task 6
Surveys of sediment chemistry were undertaken in the lake study area.

Task 7
Modeling studies were initiated to determine parameters for applications to: (1) the entrance of the Cuyahoga River into Lake Erie, and

(2) thermal discharges from power plants on Lake Erie.

Task 8
Literature survey, collection and cataloging.

Task 9
Interpretation of all individual task reports and the preparation of a comprehensive baseline information assessment report.

Although the individual tasks for the most part were accomplished producing valid baseline information, the project did leave information gaps which prevent a total comprehensive baseline assessment. The major areas that were not covered are:

1. Hydrology and water budget of the area.
2. Benthic chemistry dynamics preserving the in situ conditions.
3. Pollution dispersion patterns as related to lake currents.
4. Sedimentation contribution and patterns.

These areas will be incorporated in phase II of the program

CLEVELAND WATER QUALITY PROBLEMS

Historical Review

Water quality problems have been a part of Cleveland's history since the early nineteenth century. It is of practical value to review this early history in order to understand the existing water quality problems and proposed corrective measures. In addition, knowledge of past conditions can assist in setting water quality objectives and standards.

Prior to 1850, the only water quality problems reported for the Cleveland area concerned noticeable reductions in the populations of several fish species, notably muskellunge and pikes (White, 1973). These reductions were attributed to the construction of dams on streams in the area rather than to water pollution, but it is important to recognize that water quality changes in the Cleveland area are not all attributable to introduction of contaminants nor are they all correctable by reduction or elimination of the contaminants.

The first reliable record indicating that water pollution was becoming a problem for Cleveland occurred after 1850. In a report to the Cleveland Common Council, a special committee made the following observations and recommendations (Case et. al., 1853):

1. The community's groundwater was becoming severely contaminated as a source of drinking water.

2. The water quality of the Cuyahoga River and Lake Erie were acceptable as sources of drinking water and chemical analyses were presented (Table 1.).

3. It was recommended that a sewer system be developed to protect the purity of Lake Erie, although the sewer system was to terminate in the Cuyahoga River "below low water mark."

Between 1850 and 1900, water quality in the Cleveland area deteriorated drastically. In 1854 the City had established a drinking water intake in Lake Erie that was approximately 400 feet offshore and one mile west of the Cuyahoga River. (The existing Westerly Wastewater Treatment Plant rests very nearly on the former intake location.) Water quality data published in 1865 (Water Works Trustees, 1865) show that total solids were beginning to increase in the lake (Table 2).

By 1866, the water drawn through the water intake was badly polluted at times with industrial wastes, largely from oil refineries established along the Cuyahoga in 1864 (Water Works Trustees, 1867). One investigation reported petroleum wastes to extend one mile out in the lake from the river. Also in the 1867 report are remarks by the superintendent of the Cleveland Water Works concerning the intake contamination. His advice was that there were two courses of action that would alleviate the problem:

1. Move the water intake further out in the lake, and

2. Strictly enforce the existing water pollution ordinances.

His recommendation was for the latter course of action.

It is not evident that any vigorous water pollution control activities resulted from the recommendation of the superintendent. In the winter of 1869, petroleum wastes were reported to have contaminated the lake from bottom to surface for a distance of one mile out from the Cuyahoga and for two miles to the west and one mile to the east of the river (Water Works Trustees, 1870).

During the 1870's further evidence of continued water quality deterioration was published. In 1877 one report stated that whitefish eggs would be planted in the Cleveland area of Lake Erie, because of the scarcity of fish (White, 1973). Also, water quality data indicated further deterioration. Cleveland had constructed a new water intake in the Lake approximately 6,200 feet lakeward of the old intake. Data were collected (Water Works Trustees, 1875) to compare water quality of the new intake with that of the old (Table 3).

In 1882, the City of Cleveland experienced its first water supply problem resulting from a bloom of algae (Water Works Trustees, 1883). In mid July citizens complained of a disagreeable fishy taste and odor

Table 1. WATER QUALITY OF LAKE ERIE AND THE CUYAHOGA RIVER IN 1852.
(mg/1)

Station[a]	Date	Total solids	Loss on ignition	Earthly and saline matter
1	August, 1852	78	7	71
2	August, 1852	36	11	24
3	October, 1852	117	49	68

[a] Station 1. Cuyahoga River near its mouth.
Station 2. Lake Erie, 0.5 miles from shore and 1.5 miles east of the Cuyahoga River.
Station 3. Lake Erie, 10 feet from shore and 1.5 miles east of the Cuyahoga River.

These data indicate that Lake Erie had considerably less total solids than in the year 1900, a year generally considered to be representative of Lake Erie in an unpolluted state.

Table 2. WATER QUALITY OF LAKE ERIE IN 1865.
(mg/1)

Station[a]	Date	Chloride	Sulfate	Total solids	Loss on ignition
1	February 19, 1865	4.6	47	116	31
2	February 19, 1865	4.7	47	93	11

[a] Station 1. Lake Erie, 400 feet offshore and one mile west of the Cuyahoga River.
Station 2. Lake Erie, 3,000 feet lakeward of Station 1.

in the drinking water. An investigation revealed that the taste and odor were attributable to the "decay of a low form of aquatic vegetation, resulting subsequently in fermentation of the water." It was also stated in this account that Cleveland had been previously exempt from such a problem.

The first in-depth water quality study in the Cleveland area was conducted in 1887 (Water Works Trustees, 1887). Samples were collected from the lake during the months of July, August, September, October, and November, on four lines running outward from the shore. The first line ran outward from West 117th Street, the second from West 58th Street, the third from Marquette Avenue and the fourth from Doan Brook. On each monthly run, samples were collected every half mile out from two depths; four feet below the surface and five feet from the bottom. The samples on the four lines were all taken on the same day and usually after a heavy wind, in order to sample the lake in its worst condition. Samples were also taken from ten miles offshore and 15 miles offshore.

The data are summarized in Table 4. The general impact of the city on Lake Erie was similar to the existing impact pattern. Water quality deteriorated from west to east across Cleveland and improved with distance offshore. The completeness of the 1887 data further show that Cleveland has had a general depressing effect on the near shore water quality of Lake Erie for nearly 90 years.

During the 1890's, two significant developments occurred concerning the Cleveland sewer system. First, plans were completed for several major interceptors which established the present basic wastewater flow pattern for the city. Of most significance however is the year 1892 in which the city constructed its first sewer overflow. The first overflows were built on an experimental basis to see if undercapacity sewers could be relieved during heavy rains. The experiment was considered successful and it was stated that "The policy has now been adopted of building these overflows wherever a proper outlet for the discharge can be made available." The Cleveland sewer system presently has over 600 overflows.

From 1900 up to the present, the general types of problems and water quality consequences that became evident in the 1850-1900 period persisted. Even with the construction and periodic upgrading of sewage treatment plants in Cleveland, municipal wastes continued to be a problem because of the sewer overflows. Dredge material disposal was considered a problem as early as 1886, especially where contamination of the water supply was concerned. The Cuyahoga River was evidencing oxygen depletion late in the 19th century, and the existence of an industrial waste problem has already been discussed. Algal blooms were taking place, and discussions were held in 1904 concerning possible sanitary contamination of the water supply from watercraft.

A number of events marked the deterioration of water quality in the Cleveland area between 1900 to the present. One indication is the types

Table 3. WATER QUALITY OF LAKE ERIE IN 1873-1874
(mg/1)

Station[a]	Date	Total solids	Suspended matter
1	November, 1873	240	131
2	November, 1874	110	12

[a] Station 1. Lake Erie, 400 feet offshore and one mile west of the Cuyahoga River.
Station 2. Lake Erie, 6,200 feet lakeward of Station 1.

Table 4. WATER QUALITY OF LAKE ERIE IN 1887
(mg/1)

Distance offshore	Total ammonia	Chloride	Total solids	Oxygen consumed[a]
0.5 miles	.223	1.95	141.1	4.65
1.0 miles	.207	1.80	137.3	4.68
1.5 miles	.207	1.78	133.2	4.54
2.0 miles	.201	1.74	130.6	4.40
10.0 miles	.200	1.30	121.9	4.42
15.0 miles	.119	1.60	104.6	3.85

[a] A type of chemical oxygen demand test.

of fish populations that were affected. The fish fauna of the Lake Erie shoreline in the Cleveland area underwent several marked changes due to pollution impact. The first major impact occurred over fifty years before 1900 when local populations of Muskellunge, Northern Pike, and other desirable fish were almost extirpated. The second major impact occurred between 1860 and 1890 when the Walleye, Smallmouth Blackbass and shoreline fish such as darters and shiner suffered pronounced decline approaching extirpation. This second major development in fish fauna can be directly correlated with the rapid growth of Cleveland's gross pollution of the Cuyahoga River. The third major development was the rapid reduction of Sturgeon in 1913 followed by the drastic decline of Cisco by 1929. The pollution remained relatively constant for the next twenty years with commercial fishing exerting a marked stress on the various fish populations (Regier and Hartman, 1973). The most recent impact on Cleveland area fish fauna occurred in the 1950's. The principal species affected were the Blue Pike, the Yellow Walleye, and the Burbot together with other valued food species that suffered pronounced decline and near extinction in the Cleveland area waters.

A number of factors affected the decline of certain types of fish fauna in the nearshore waters of Cleveland. The pollution loadings from municipal and industrial sources were a major cause of the decline. Other factors amplified the effects. These factors were damming of streams physically, sediment loadings from exposed urban areas, accelerated erosion and subsequent choking of spawning areas with silt and clay from cleared woodlands, destruction of spawning areas such as nursery marshes, and the added stress of the commercial fishing industry. As a result of the total impact of all these factors the fish fauna of the area changed from clean water forms and highly valuable food fishes, such as Muskellunge, Walleye, Lake Trout, Silver Chub and Burbot, to rough pollution tolerant and low value food fishes such as the Goldfish, Carp, Gizzardshad and Perch.(White, 1973). A more detailed historical treatment is contained in Volume II , and in Regier's and Hartman's article listed in the bibliography.

In terms of gross water quality deterioration in the Cleveland area, as well as most of Lake Erie, the main impact from 1900 to the present came from municipal and industrial discharges which were and are directly proportional to the growth of the industry, commerce, and population in the Cleveland area and in the Lake Erie watershed. The excessive nutrient loadings from these sources produced a plankton succession in the lake. This succession occurred over a period of a hundred and fifty years, and it is a definite qualitative indicator of eutrophication.

The qualitative succession progressed from oligotrophic forms of Asterionella and Synedra occurring in the phytoplankton pulses in spring and fall to the eutrophic forms Melosira and Fragilaria. For the last three years the dominant forms in plankton pulses have become the blue-green algae - Anabaena, Microcystis, and Aphanizomenon. (Davis, 1964)

Table 5. COMPARISON OF CHANGES IN WATER QUALITY REPORTED IN COMMERCIAL FISHING REPORTS
(ppm)

	Lake Erie				
Year	SO_4	Cl	Ca	Na-K	Dissolved solids
1908	13	8	31	6	133
1939	22	15	38	7	165
1949	22	17	33	7	167
1960	22	20	36.4	12	205

Lake Erie waters described as bicarbonate (total alkalinity of 95 ppm as $CaCO_3$) and similar to the average fresh waters of the world. Average pH is 8.3 and specific conductance at 18°C is 242 umhos. (N.B. This would mean a dissolved solids concentration of 157 ppm rather than 205 reported.)

Table 6. CHLORIDE LEVELS OF LAKE ERIE TRIBUTARIES IN 1904
(mg/1)

Location	Date	Chloride
Detroit River, South of Grosse Island	July 12, 1904	3.0
Maumee River, mouth	August 27, 1904	24.6
Portage River, Woodville	September 11, 1904	23,240.0
Sandusky River, above Tiffin	September 11, 1904	410.0

Quantitatively average summer densities have increased by a factor of three, but the total biomass production has increased by a factor of twenty since 1919. Figure 2 shows the quantitative relationships of biomass production increase. The plankton succession and increase produced profound effects on the hypolimnetic waters in terms of oxygen depletion. The dissolved oxygen dropped in the summer from 9 mg/l to 1 mg/l due to the plankton dying and sinking to the bottom, and subsequently decomposing. Consequently benthic organism succession occurred from clean water forms to low oxygen tolerant forms such as oligochaetes and chironomids.

The water quality deterioration in the Cleveland area between 1850 and 1900 was delineated to place the early conditions of Lake Erie in proper perspective. This is necessary information in the establishment of water quality objectives. The former Federal Water Pollution Control Administration in its 1968 "Lake Erie Report" traced the increase of several Lake Erie chemical constituents from the year 1900, see Table 5. The curves generated for chlorides and total dissolved solids were deceptive in that they indicated increases did not begin until after 1900. In fact, chlorides had nearly tripled during the 1850 to 1900 period, and total dissolved solids increased during the same period by 50% to 100%.

The increase in solids during the 1800's is attributable to urban industrial wastes for local areas, but overall increases in the lake were caused by brine discharges from the developing oil fields in northwestern Ohio. Some of the streams tributary to the lake at that time had staggering chloride loads. The following data in Table 6 (Whipple, 1905) illustrate the problem.

These early levels need to be considered if Lake Erie water quality improvement is considered to be a problem of restoration in addition to a problem of waste input reduction. Restoration objectives might differ considerably from present guidelines. For instance, the 1972 Great Lakes Water Quality Agreement with Canada sets the Lake Erie dissolved solids objective at 200 milligrams per liter when in 1850, the dissolved solids were at about half that level. Also in 1972 the U. S. Environmental Protection Agency proposed Lake Erie Standards which included a recommendation that chlorides should not exceed 30 milligrams per liter. In the mid-nineteenth century, chloride levels were very likely less than one tenth the recommended level. Also, as pointed out earlier, many changes in the Lake occurred from disturbances other than waste input. A true restoration program would have to consider aspects such as removal of dams and wetland restoration if the original high quality fish populations are to be obtained.

Further consideration of overall Lake Erie standards and objectives are beyond the scope of this study, but as part of the study many early data have been made more accessible for use by necessary agencies. These data and sources have been catalogued at the Sears Library of Case Western Reserve University.

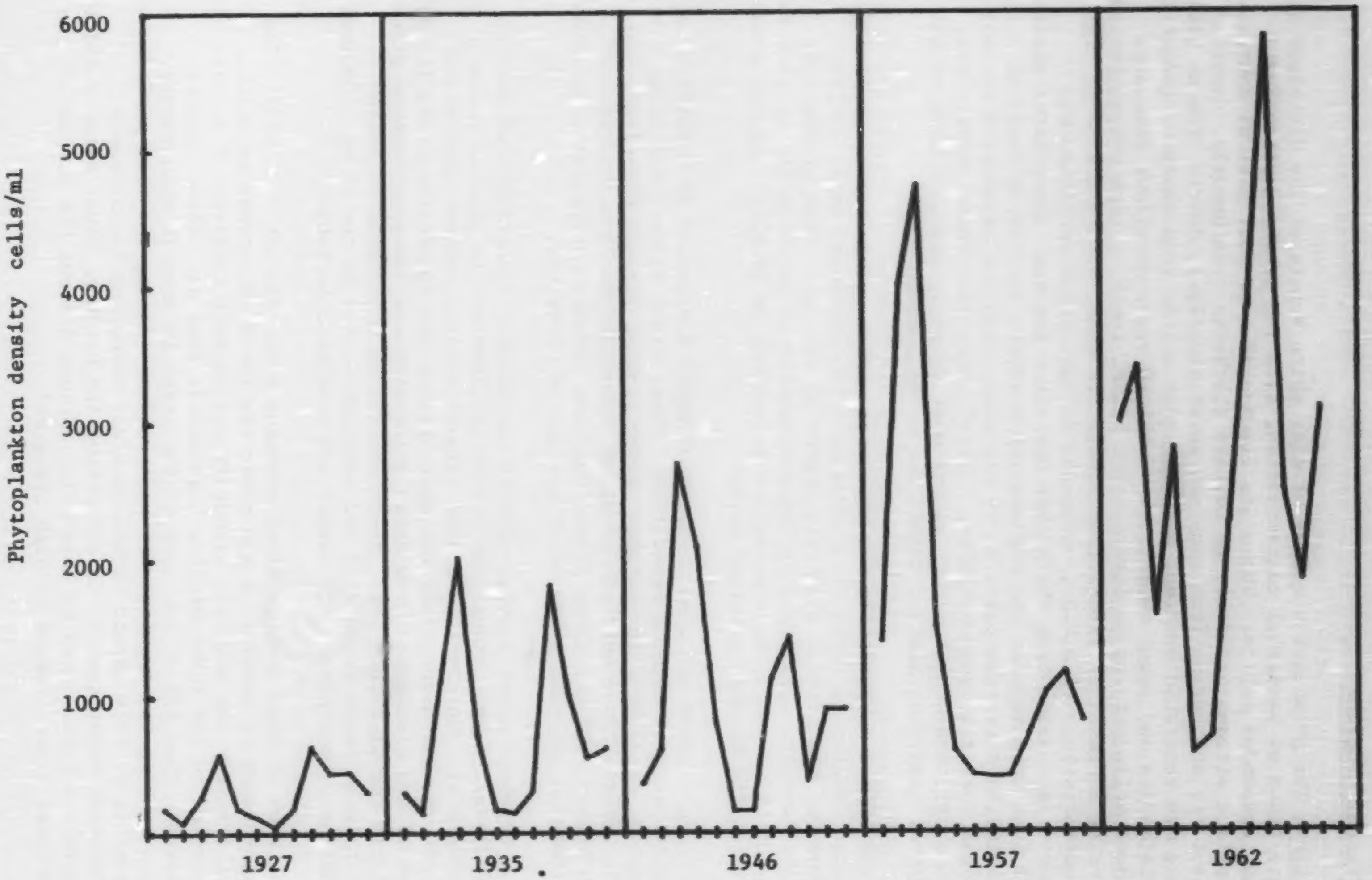


Figure 2. Monthly averages of phytoplankton abundances for selected years showing the trend

Present Problems

Lake - The principal problems of near shore waters of the Cleveland area are those of bacterial contamination, floating debris, eutrophication and suspended solids. These are discharged from four general sources. Surface streams and drainage courses discharge continuously, carrying bacteria and sewage from combined sewer overflows, debris from natural and man generated sources, and suspended solids from erosion, industrial discharges and sewer overflows. Combined sewer overflows discharge these pollutants on an intermittent basis, reaching high concentrations during storms. Effluents from sewage treatment plants discharge high concentrations of B.O.D., suspended solids, plant nutrients and bacteria. Water from the harbor depresses the near shore water quality of Lake Erie because the predominant westerly winds move residual polluting materials parallel to the shore from the Cuyahoga River and local combined sewer outfalls. All of these discharges occur close to shore, and affect water quality most severely within a mile of the shore, rendering beaches unsafe for human contact.

Fish life is abundant in the near shore area, and is not controlled by water quality in terms of occurrence. The depressed water quality areas do not prevent fish from migrating through. Most of the fish life however, are primarily low desirability food value fishes such as goldfish or carp. Eutrophication is evident in locally stagnant areas especially in the Cleveland Harbor.

Streams - Cleveland area in terms of water management is treated as one watershed with natural boundaries. Three major rivers, the Rocky River west of Cleveland, the Cuyahoga River running through Cleveland, and the Chagrin River east of Cleveland, comprise the Three Rivers Watershed. Of the three rivers only the Cuyahoga evidences a profound effect on the near shore water quality of Cleveland.

The Cuyahoga River flowing through the heavily industrialized section of Cleveland and through the center of Cleveland is grossly polluted by industrial, municipal, and agricultural sources besides land runoff. Above the Cleveland area, the main sources are agricultural and land runoff and discharges from Akron's industry and sewage treatment plants. Within the Cleveland area, there are twelve major sources which contribute heavy industrial and sanitary wastes to the river. Sources and their approximate discharges are tabulated in Table 7.

The flow of the Cuyahoga River averages about 850 cfs (550 mgd). The major users of water from the river are the steel companies which collectively use 400 mgd, primarily for contact cooling. This water is recycled to the river bearing high solids loading. These figures indicate that 73% of the flow of the river is used in this manner, illustrating the magnitude of the problem. During low flow periods, severity of this impact is intensified, resulting in extremely depressed water quality in and around the Cuyahoga River estuary and the Cleveland Harbor area of Lake Erie. Figure 3 shows the portion of the Cuyahoga River flowing through Cleveland.

Table 7. SOURCES AND DISCHARGES TO CUYAHOGA RIVER

Source	Flow (mgd)	Suspended solids (lbs/day)	Total solids (lbs/day)	Total P (lbs/day)
Southerly Waste Treatment Plant	115	14,000	360,000	3,300
U. S. Steel (Cuyahoga Works)	12	10,000	25,000	100
Big Creek	30	33,000	150,000	500
Harshaw Chemical Co.	1.5	88	32,000	nil
Jones & Laughlin Steel	130	80,000	885,000	1,100
Republic Steel (2 plants)	200	370,000	--	1,700
E. I. Dupont de Nemours	5.7	800	14,000	--
Kingsbury Run	3.2	500	16,000	40
U. S. Steel (Central Furnace)	59	40,000	370,000	490
Walworth Run	--	1,000	10,000	50
Republic Steel (Nut & Bolt Div.)	2.7	18,000	--	--

Note: 1968 data still valid as spot checked in 1973.

Figure 3. Segment of the Cuyahoga River flowing through downtown Cleveland.

The river in the Cleveland area is devoid of fish life, except in a few isolated areas where small colonies of goldfish exist. Within the greater Cleveland area there are eleven streams of significant size which discharge to the lake or Cuyahoga River. These eleven streams contribute an annual total of over 125,000,000 pounds of solids containing nearly 30,000,000 pounds of B.O.D. and C.O.D. to Cleveland waters. Table 8 summarizes the yearly loadings of the various creeks. Most of the streams are heavily degraded physically and biologically. Only pollution tolerant biologic forms are able to survive in selected streams. The physical degradation is caused by culverting, channelization, diversion, damming, and waste dumping. Most of these streams, however, can be restored.

General - As a separate entity, one of the biggest sources of pollution to the Cleveland area is combined sewer overflows. Estimation of the loadings are about 5% of the annual flow to the treatment plants, or about 5.5 billion gallons annually. Loadings for this discharge are given in Table 9.

Another definite problem is the disposal of dredgings from the Cuyahoga River inside dikes constructed in the Cleveland Harbor. These dredgings contain pollutants that are under anoxic conditions released into the water. With the thermal discharges released by the municipal power plant localized eutrophic conditions are created. Other problems, other than direct discharges, are produced by polluted leachate emissions of the waste fills along the eastern shore in the Harbor. Around those areas the water quality is heavily degraded.

Pollution Abatement Measures

In Progress - A general approach to solving pollution problems of the Greater Cleveland area has been formulated into an extensive regional plan, and many steps are presently underway. Industrial sources of pollution are being abated through various approaches, by either in-plant treatment or by channelling the wastes to the municipal sewer systems for treatment. Sewers and interceptors will be enlarged to handle these flows and prevent combined sewer overflows and local flooding. Before being discharged to Cleveland waters, these flows will be treated at new or upgraded treatment plants.

A program of industrial pollution abatement has been in progress since 1969 through efforts of the Cleveland Water Quality Program, which is an organizational unit in the Division of Utilities Engineering of the City of Cleveland. A total pollution survey was made, and all sources traced. Negotiations by the Program with industries started the abatement project. Industrial concerns surveyed their operations and submitted plans to reduce or eliminate discharges. In-plant modifications, process changes, recycling, construction of private treatment facilities, and discharging wastes to the Cleveland sewer system were discussed.

Table 8. LOADS TO RECEIVING WATER FROM STREAMS
(pounds per year)

Stream	BOD	COD	Total solids	Suspended solids	Total PO_4 as P	NO_3 as N
Dugway Brook	209,100	1,887,000	10,250,000	883,300	25,500	32,900
Doan Brook	205,800	5,365,500	12,045,000	1,014,700	18,200	29,200
Big Creek	1,573,100	9,344,000	40,880,000	4,489,500	116,800	182,500
Nine Mile Creek	237,200	2,675,400	14,750,000	4,270,200	27,400	51,100
Shaw Brook	31,700	592,000	1,887,000	376,600	5,400	15,700
Kingsbury Run	127,750	656,000	8,468,000	3,148,100	9,100	51,100
Morgan Run	91,600	671,600	4,307,000	602,200	12,700	5,800
Green Creek	4,600	36,000	560,000	50,000	170	980
Burke Brook	42,700	196,000	2,682,700	325,500	365	4,020
Mill Creek	49,200	746,400	4,982,200	375,950	4,740	18,200
Euclid Creek	235,400	4,617,200	25,002,500	6,048,000	25,500	171,500
Total	2,808,150	26,787,100	125,814,400	18,584,050	245,875	563,000

Note: 1968 data still valid as spot checked in 1973.

Table 9. POLLUTION LOADINGS FROM COMBINED SEWER OVERFLOWS
(pounds)

Pollutant	Total annual discharge
C.O.D.	23,900,000
$B.O.D._5$	7,510,000
Suspended solids	14,320,000
Total solids	41,680,000
Phosphorus (as P)	1,098,000
Total nitrogen (as N)	1,606,000

Note: 1968 data still valid as spot checked in 1973.

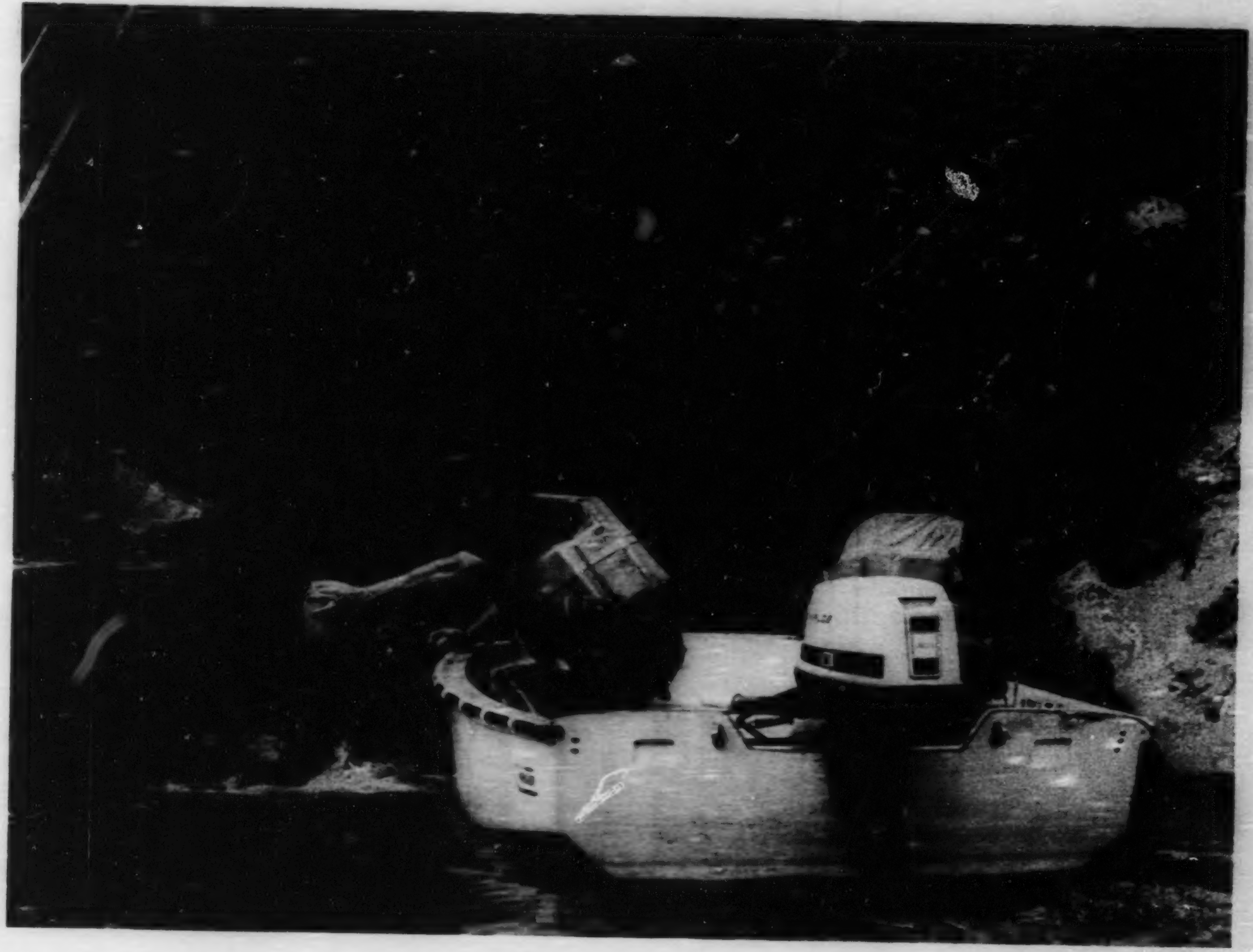


Figure 4. Sampling industrial outfalls on the Cuyahoga River. (Note that the river bank is a sediment contributor.)

At present, about 40% of the 112 industries discharging to surface waters have ceased their discharges. Most of these industries, however, are smaller operations, while larger companies are in the planning or construction stage, or are awaiting court decisions before undertaking projects.

In August of 1973 the program was revised and revitalized to provide a more dynamic and comprehensive base for effective goal achievement. The program (Figure 5.) called Industrial Discharge to Streams Abatement Program incorporates adjustments to federal and state programs pursuing similar goals. Presently, this program is being closely coordinated with the Ohio Environmental Protection Agency's activities on the requirements of section 303E of the 1972 Federal Water Pollution Control Act; PL 92-500. Closely associated with these activities urban stream restoration feasibility studies are being undertaken.

In July of 1972 the Cleveland Regional Sewer District was formed consisting of Cleveland and 33 suburbs. Raymond Kudukis, President of the Board of Trustees of the Cleveland Regional Sewer District, described this development in the September, 1973 issue of Water and Wastes Engineering publication:

> The District cuts across political boundaries and jurisdictions and therefore is in a unique position to be able to plan anti-water pollution projects without fear of being stymied by local political considerations. It is run by a seven member board of trustees through a director appointed by the board. Four representatives from the Cleveland subdistrict and three from the suburban subdistrict make up the board.
>
> The Sewer District has taken over operation of the city's three major sewage treatment plants, which together treat about 300 mgd, and is continuing programs started by the City of Cleveland. In order to meet standards set by the Federal Water Pollution Control Act Amendment of 1972, this means upgrading the treatment plants and improving the collection system with an extensive network of sewers, trunks, mains, and interceptors. Much of the work aimed at achieving advanced wastewater treatment is already underway and limited only by the availability of federal funds.
>
> At the core of Cleveland's efforts to achieve water quality are the Easterly, Westerly, and Southerly Wastewater Treatment Plants and their collection systems.

The Cleveland Regional Sewer District will simplify the implementation of expansion and upgrading of waste treatment facilities and collection systems. Plans for five large interceptors to carry the wasteload to treatment plants are either completed or being implemented, with just a few minor details yet to be negotiated. A small sewer project is developed which sets repair or replacement priorities on all area sewers. Permanent rain gauges relaying precipitation data instantly to a computer are installed around the greater Cleveland area for monitoring flow in the sewer system. (See Figure 6.)

On October 26, 1972, the Cleveland Regional Sewer District adopted Resolution No. 15-72 establishing an industrial waste sewer charge. The charge to industrial users of facilities in the Cleveland Regional Sewer District becomes effective January 1, 1974. The District has contracted the Water Quality Program of the Division of Utilities Engineering of the City of Cleveland to design and implement this charge.

The industrial waste charge has been instituted to a large degree in response to the "Federal Water Pollution Control Act Amendments of 1972." Title II of the Act (Grants for Construction of Treatment Works). Section 204 (b) (1) (B) which reads in part that no construction grants for treatment works shall be approved unless provision has been made to receive payment from industrial users of treatment works for "that portion of the cost of construction of such treatment works which is allocable to the treatment of such industrial wastes." Maintenance of eligibility to receive Federal construction grants for improvements of of wastewater treatment facilities remains an important part of the Cleveland Regional Sewer District's water pollution control program.

Proposed - By the end of 1973, it is estimated that 75% of industries discharging to Cleveland's waters will have ceased their discharges. The major polluters of the waterways are expected to construct treatment facilities as soon as court decisions and consent decrees are expedited.

The proposed plan to eliminate sanitary and storm sewage overflow contains two approach methods. First, since much of the sanitary load to the treatment plants originates in the suburbs, five new interceptors will be built to carry this waste express to the plants. This will relieve the overburdened Cleveland combined system of suburban wastes, providing larger capacity for Cleveland discharges and eliminating 100% of dry weather overflows. The Northwest Interceptor, costing $23 million is underway, with Southeast, Southwest, Cuyahoga Valley and Heights Interceptor projects to follow. The other basic approach involves more efficient use of the present system. A system of inflatable dams strategically placed within existing interceptor, and operated by computer, will throttle heavy flows during storm conditions. These "Fabri-Dams" respond to the data generated by the rain gauge stations. Combined with proposed storm flow storage basins, they will be able to handle 95% of a ten year storm by automatically inflating and deflating to regulate or divert flows. (See Figure 7.)

With improved collection and transport facilities, the treatment plants must be upgraded to treat the increased volume of waste, and consonant

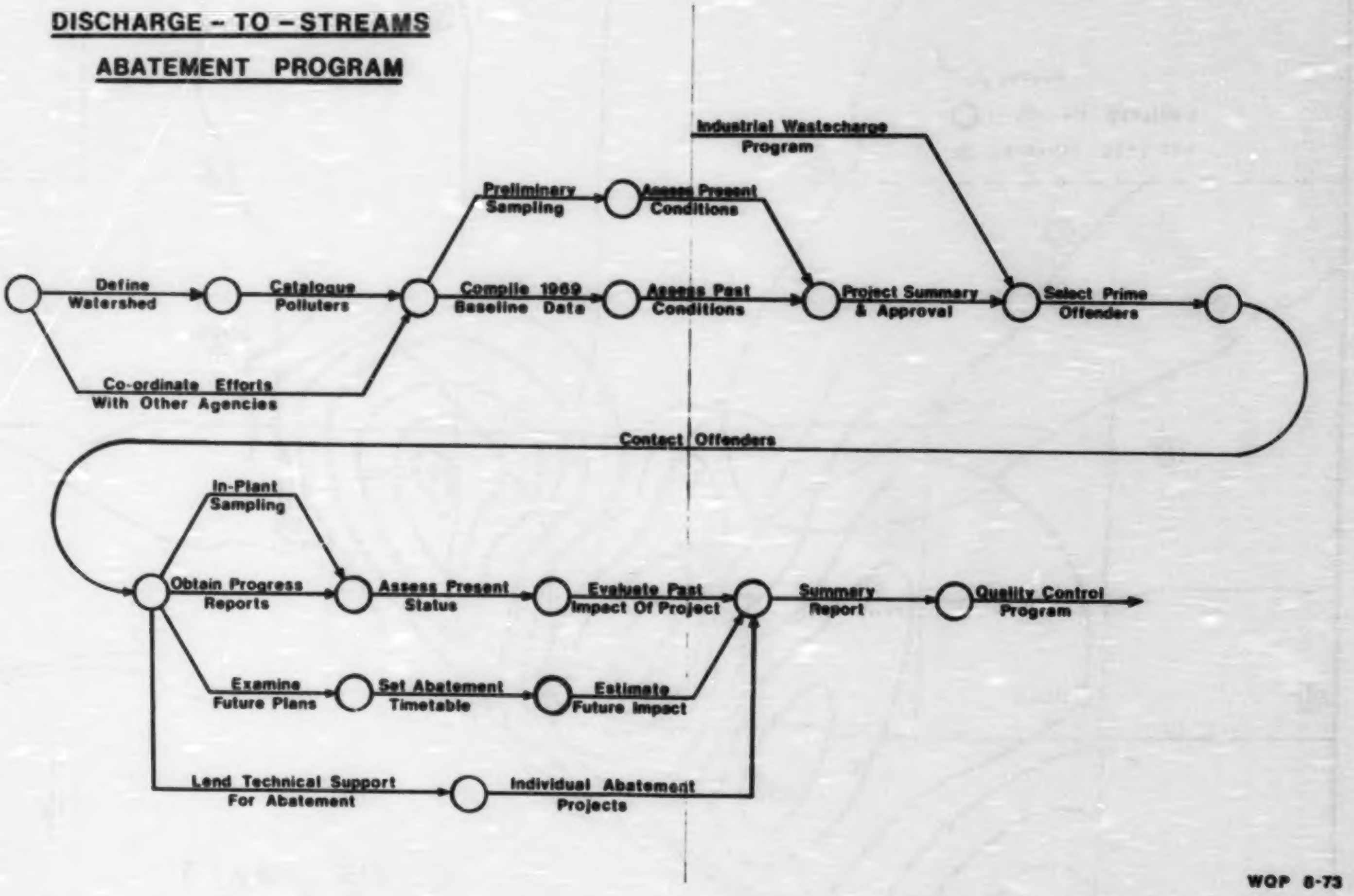
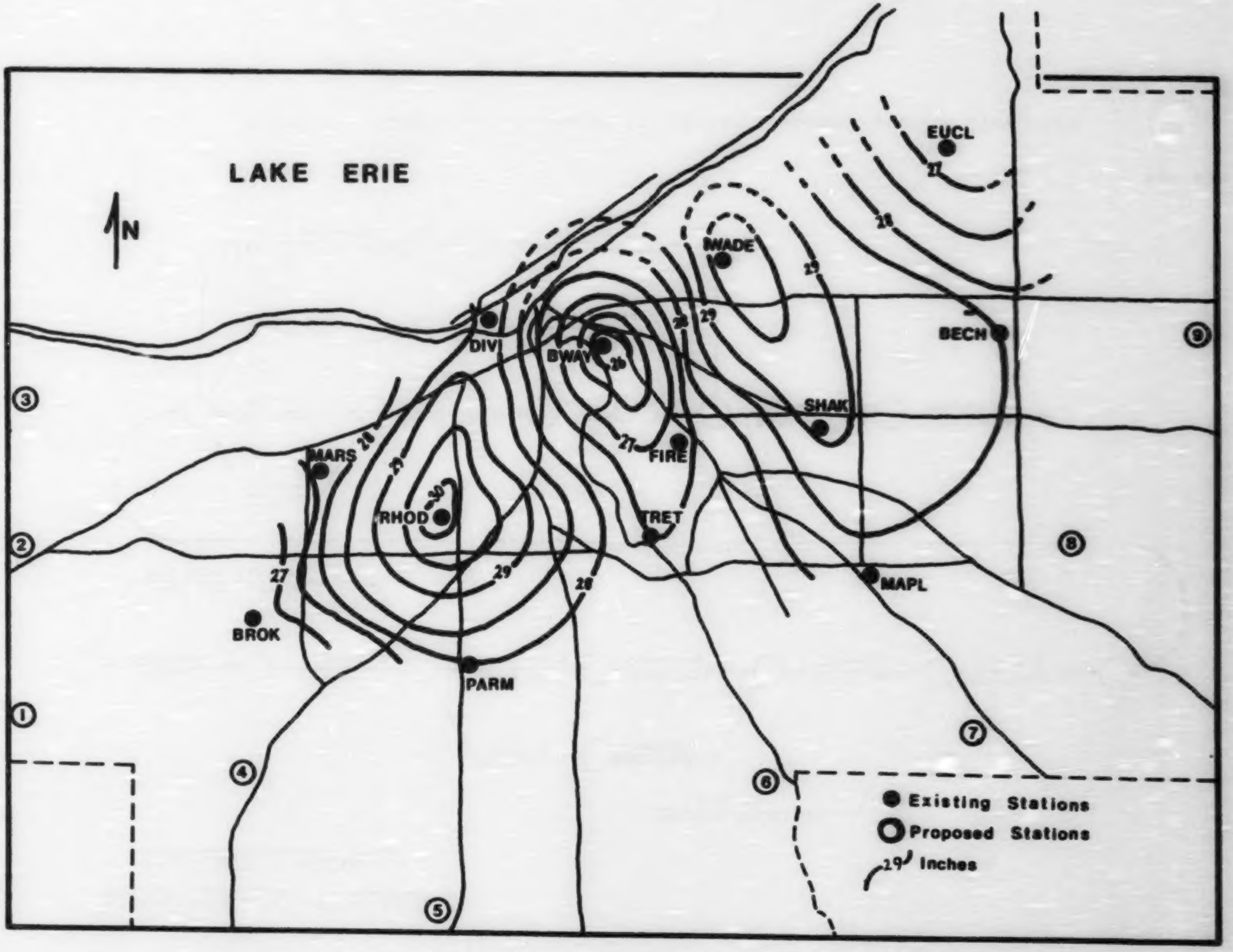

DISCHARGE - TO - STREAMS
ABATEMENT PROGRAM
Define Watershed
Catalogue Polluters
Co-ordinate Efforts With Other Agencies
Preliminary Sampling
Compile 1969 Baseline Data
Assess Present Conditions
Assess Past Conditions
Industrial Wastecharge Program
Project Summary & Approval
Select Prime Offenders
Contact Offenders
In-Plant Sampling
Obtain Progress Reports
Assess Present Status
Evaluate Past Impact Of Project
Examine Future Plans
Set Abatement Timetable
Estimate Future Impact
Lend Technical Support For Abatement
Individual Abatement Projects
Summary Report
Quality Control Program
WOP 8-73

Figure 5. Industrial discharge to streams abatement program flow chart.


LAKE ERIE
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RHOD
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29
28
MAPL
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PARM
1
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3
4
5
6
7
8
9
Existing Stations
Proposed Stations
29 Inches

Figure 6. Nine month total precipitation (February to October 1973)
Points shown are rain gauge stations.

with water quality standards, improve treatement efficiency. The three Cleveland Regional Sewer District wastewater treatment plants, Easterly, Southerly, and Westerly, are being upgraded for these objectives.

Easterly plant - The existing 140 mgd Easterly Plant which has provided both primary and secondary treatment since it was built as a WPA project in the 1930's is undergoing an expansion program which will increase its design capacity to a dry weather flow of 170 mgd with the capability of treating 380 mgd wet weather flow. Flows in excess of 380 mgd will be diverted by new headworks under construction to storage basins for subsequent treatment.

Advanced wastewater treatment techniques including chemical treatment are being included in the Easterly design expansion by the design engineers, Havens and Emerson, Limited. Primary plant expansion has been completed and expansion of the secondary plant, begun by the City of Cleveland, will continue in phases with completion scheduled for 1976.

On January 3, 1973, the Cleveland Regional Sewer District was awarded a grant from the Federal Environmental Protection Agency for the construction of the new headworks and pretreatment facilities.

On May 3, 1973, the Board of Trustees of the Cleveland Regional Sewer District awarded an $11.9 million dollar contract for this construction to the J. M. Foster Company. The next two phases of the Easterly expansion will consist of a new effluent pumping station and new effluent conduit which will place the plant effluent into Lake Erie some 4,000 feet off shore and will provide 35 minutes of chlorine contact time to the effluent before it reaches the Lake.

Future projects include storm water storage facilities and applications of advanced wastewater treatment techniques to provide tertiary treatment.

Plans for advanced treatment facilities include phosphorus removal, and microstraining or filtering of secondary effluent.

The Easterly Plant expansion ranks fourth on the current priorities list of Ohio projects for Federal grant financing and $7.5 million dollars in Federal funding has been earmarked for the Easterly expansion in fiscal 1974. (See Figures 8 and 9)

Southerly plant - The 115 mgd Southerly Plant is the largest existing treatment plant in the Cleveland area and presently provides both primary and secondary treatment. A total redesign of the Southerly Plant to provide increased treatment capacity, advanced waste treatment, is currently being performed by Malcolm Pirnie, Inc., Consulting Engineers. Capacity of the Southerly Plant will be expanded to 200 mgd dry weather flow with capacity of providing treatment for up to 960 mgd wet weather flow.

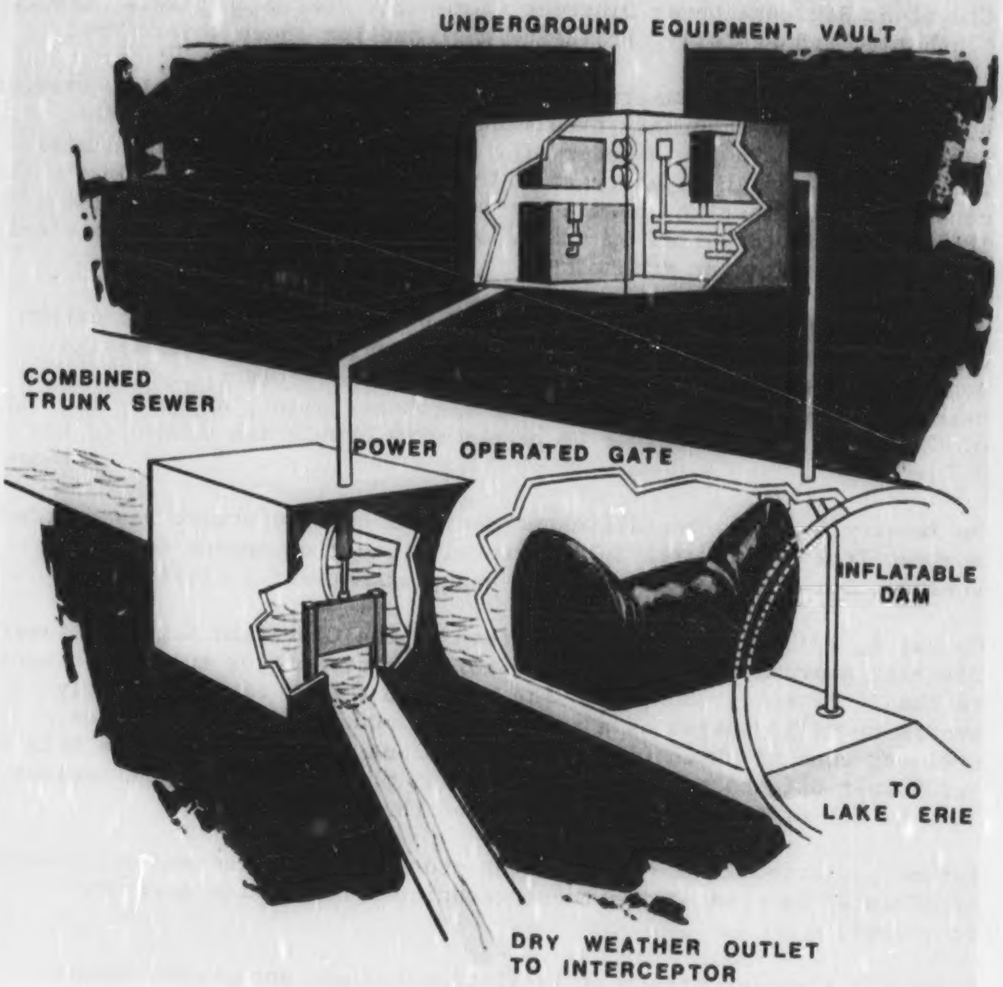
UNDERGROUND EQUIPMENT VAULT
COMBINED TRUNK SEWER
POWER OPERATED GATE
INFLATABLE DAM
TO LAKE ERIE
DRY WEATHER OUTLET TO INTERCEPTOR

Figure 7. A typical automated regulator-overflow control. The inflatable dam, shown in the storm water outlet, is made of a rubber coated fabric which is resistant to puncture, weathering and wastewater degradation. The dam is attached to a poured concrete base and to the walls of the existing sewer using clamping bars held in position with anchor bolts. An inflation pipe and pressure sensing line run from the dam to an underground vault. Inflatable dams are used in order to minimize modifications of the existing sewer and to assure that upon opening (deflating) the full section of the storm water overflow is available for conveying extreme storm flows. (Watermation, Inc.)

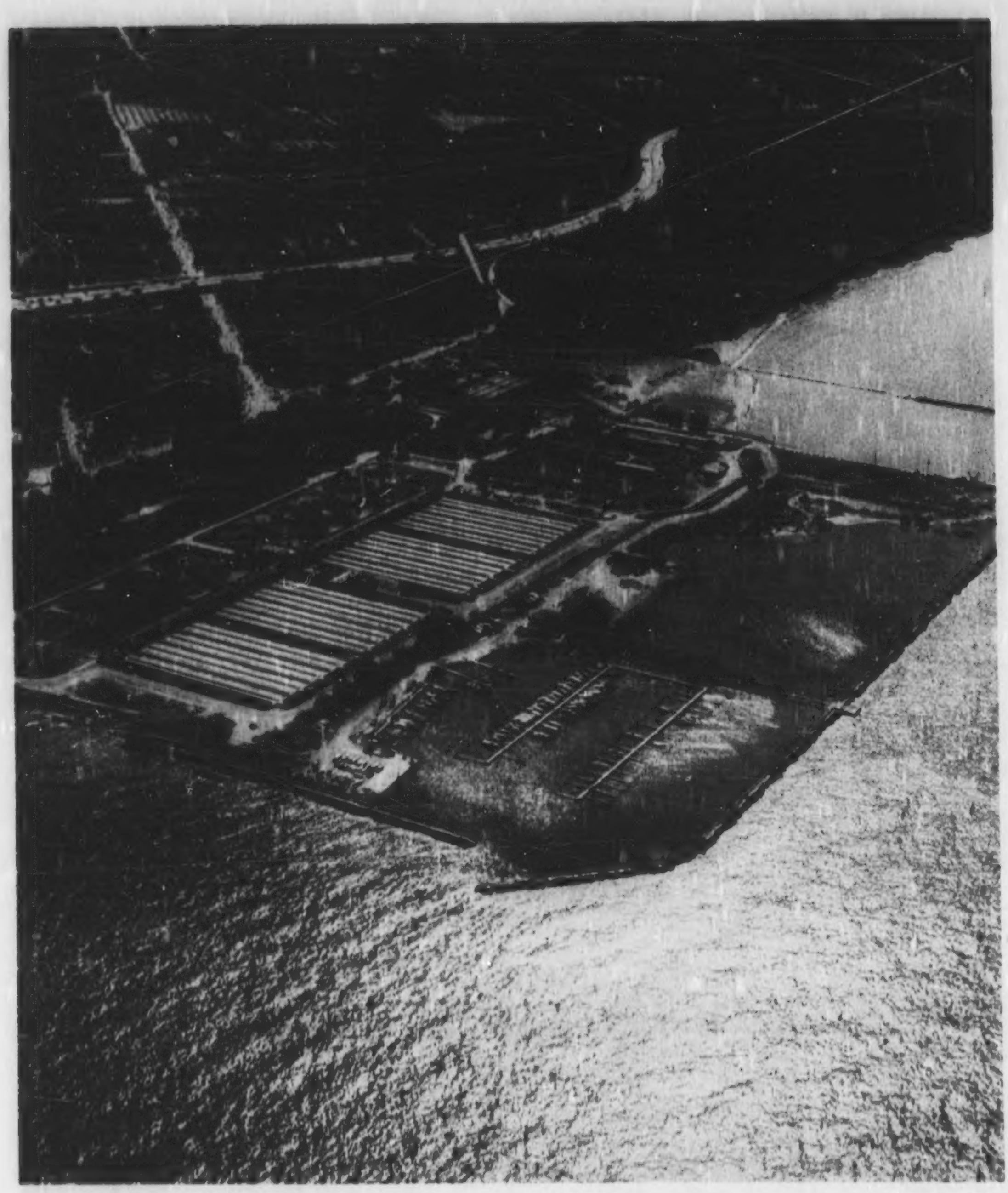

Figure 8. Aerial view of the present Cleveland Easterly Water Pollution Control Plant

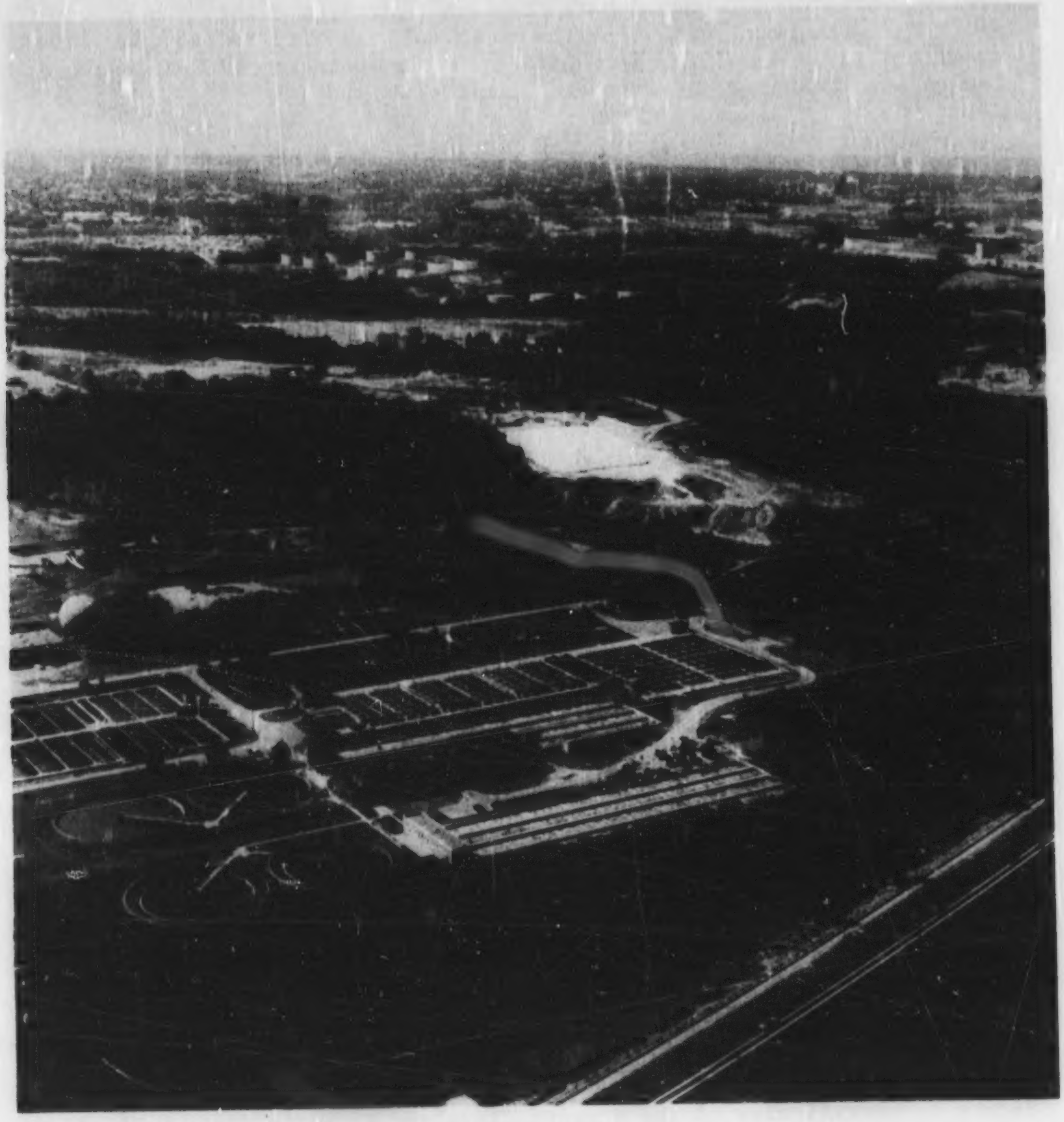

Figure 9. Aerial view of the present Cleveland Southerly Water Pollution Control Plant.

All flow into the plant up to 400 mgd will have complete treatment and flow in excess will have the equivalent of primary treatment with provisions allowing the addition of organic and for inorganic flocculation.

A biological treatment process combining standard primary and secondary treatment with advanced wastewater treatment processes to provide tertiary treatment is planned for the new Southerly Plant. When completed, the plant will have the necessary capacity to provide treatment for most of the communities in the southern half of Cuyahoga County and some parts of northern Summit County.

The Southerly Plant expansion ranks first on the priority list of Ohio projects for Federal funding for the current fiscal year. Since the Southerly project is now in the first stages of design and a phased construction program is planned, $10 million dollars has been allocated for Federal funding for fiscal 1974. The additional monies will be allocated in succeeding fiscal years with completion of the new plant scheduled for 1978.

Westerly plant - The existing 35 mgd Westerly Plant is the oldest of the three treatment plants and provides only primary treatment. The use of chemical treatment aids has, however, enabled the plant to provide treatment despite the large concentration of industrial wastes which the plant receives. The Westerly Plant will be completely replaced by a new 50 mgd physical-chemical plant which will be the largest operation of its kind in the world and will be the first to apply physical-chemical treatment to a large industrial flow.

The operating principle consists of primary sedimentation followed by addition of lime. The lime will achieve phosphate removal by converting phosphorus into insoluble calcium phosphate. Organic polyelectrolytes will be added as the wastewater enters a flocculation-clarification stage. This will provide a high solids removal efficiency. The pH wil then be adjusted by recarbonation.

Additional solids removal will be achieved by filtration followed by organic removal with carbon adsorption columns. Ozonation may be used for disinfection and additional B.O.D. removal.

Design engineers of the new Westerly Plant are Zurn Environmental Engineers.

The estimated cost of the new Westerly Plant is approximately $40 million dollars and it has been approved for Federal funding by the United States Environmental Protection Agency. The Board of Trustees awarded the first contract for the new plant, a $3.5 million dollar sludge incineration equipment contract, to Envirotech Systems, Inc. of California on January 11, 1973. The second construction contract for the new incinerator building and chemical building will be bid in the fall of 1973. The final construction contract (Contract III and IV) consisting of headworks, clarifiers and filters, will be bid in early 1974 and the new plant is scheduled to be in operation by late 1976.

Effectiveness-Effluent Quality - With proposed industrial effluent upgrading or elimination, it is predicted that the Cuyahoga River could support aquatic life (A) if bottom sediments do not produce toxic effects on the biota. At present, 1.22 million yards of material are dredged annually from the Cuyahoga and Cleveland Harbor. With removal of the steel industries' discharged wastes, this should reduce the volume by nearly 50%, solving not only a water quality problem, but also diminishing a disposal problem connected with the dredgings.

The three upgraded wastewater treatment plants will considerably reduce pollution loadings. With the new Easterly facilities, removal of B.O.D. and suspended solids will be 95% each, and the removal of phosphorus will be 85%. Southerly will achieve the same removal efficiency. Westerly will have a B.O.D. removal capacity of at least 90% and a suspended solids removal of at least 95%. Removal of phosphorus will be no less than 85%.

SUMMARY OF FINDINGS

The limits of the study area were established to determine if possible the overall impact of the Cleveland metropolitan area on the near-shore waters of the lake. These limits are shown in Figure 10. The area extended from Lakewood Park on the west to East 222nd Street (Moss Point) on the east. The offshore limit of the study area was generally considered to be the ten meter depth line, although some samples were collected from areas of greater depth.

In addition to the area given for the lake itself, important tributary sources of wastes to the lake were also studied. These sample locations are also shown in Figure 10. All routine sampling stations for the study are described in Tables 10 and 11.

The overall results of the baseline study were not unexpected in that there was a measureable impact of the Cleveland area on Lake Erie near-shore waters. The general impact pattern was much the same as in 1886 - water quality deteriorated from west to east across the Cleveland area and improved with distance offshore. What was unexpected, however, was localized degradation in water quality along the Cleveland lakefront itself, correlated largely with point sources of waste discharge. The lakefront along Cleveland has been considered to be a homogeneous area of severely depressed water quality. In effect, there are several zones of severe water quality deterioration in Cleveland and several zones of marginal quality, with good water quality both to the immediate east and west of Cleveland. These depressed areas are identifiable most readily by the sediment chemistry and benthic organisms present. It is of interest to note that even after 100 years of continuous waste input, the areas presently showing depressed water quality are correlated with present point sources.

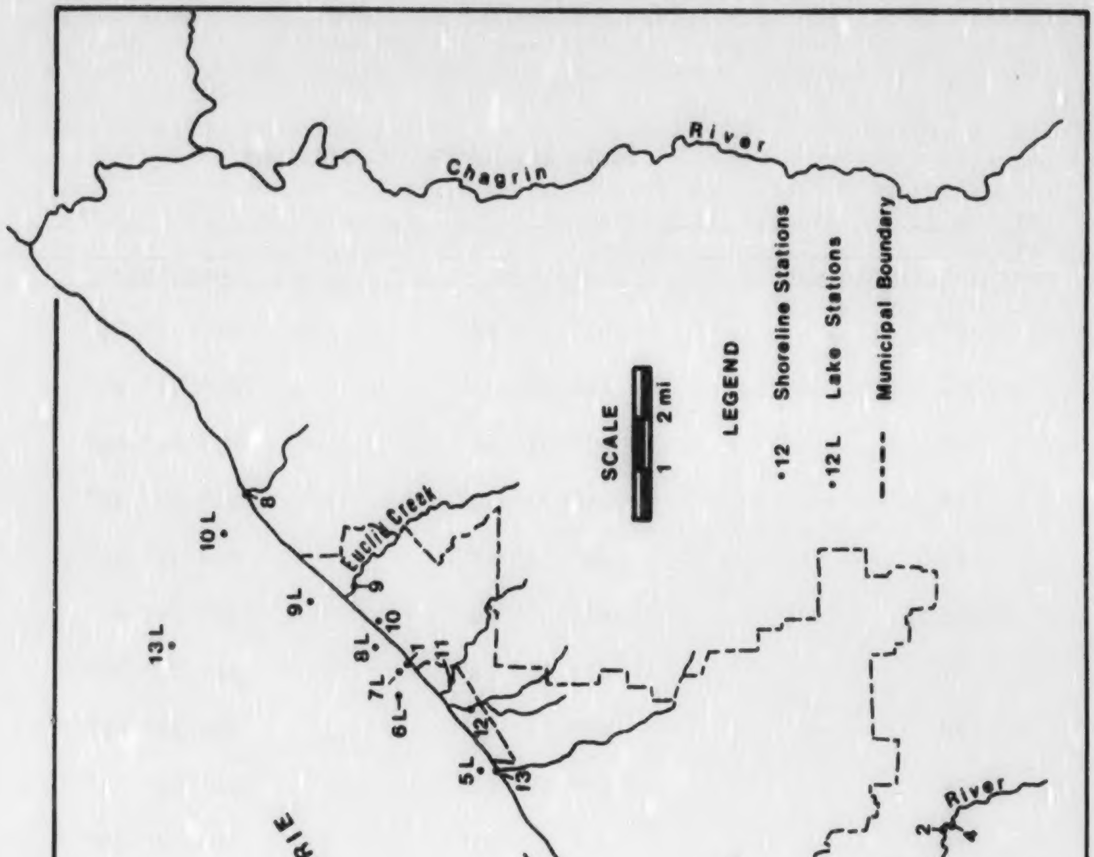
LAKE ERIE
CLEVELAND
Chagrin River
Cuyahoga River
Rocky River
Euclid Creek
N
SCALE
1
2 mi
LEGEND
•12 Shoreline Stations
•12 L Lake Stations
Municipal Boundary
1L
2L
3L
4L
5L
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Figure 10. Area covered by the study showing sampling stations

Table 10. SAMPLING STATIONS

Lake Stations	Latitude	Longitude
#1	41° 30' 12"	81° 47' 41"
#2	41° 29' 55"	81° 43' 44"
#3	41° 31' 17"	81° 41' 49"
#4	41° 32' 10"	81° 39' 32"
#5	41° 32' 48"	81° 37' 51"
#6	41° 33' 40"	81° 36' 44"
#7	41° 34' 18"	81° 35' 38"
#8	41° 34' 57"	81° 34' 46"
#9	41° 35' 47"	81° 33' 53"
#10	41° 37' 02"	81° 32' 03"
#11	41° 32' 14"	81° 47' 41"
#12	41° 33' 04"	81° 44' 47"
#13	41° 39' 35"	81° 34' 28"
#14	41° 30' 03"	81° 43' 28"

Table 11. SAMPLING STATIONS

Shoreline Stations	
#1.	Easterly Effluent Lat. 41° 34' 14" Long. 81° 35' 16"
#2	Southerly Effluent River Mile 11.0
#3	Westerly Effluent Lat. 41° 29' 38" Long. 81° 43' 39"
#4	Cuyahoga River, Railroad Spur River Mile 11.2
#5	Cuyahoga River, River Smelting River Mile 8.3
#6	Cuyahoga River, Lower Harvard River Mile 7.2
#7	Cuyahoga River, Center Street River Mile 1.0
#8	Euclid Park, East 222nd Street Lat. 41° 36' 52" Long. 81° 31' 45"
#9	Euclid Creek, Lakeshore Boulevard River Mile 0.6
#10	Green Creek, Lakeshore Boulevard River Mile 0.1
#11	Nine Mile Creek, Lakeshore Boulevard River Mile 0.4
#12	Dugway Brook, Lakeshore Boulevard River Mile 0.4
#13	Doan Brook, Gordon Park River Mile 0.0

The areas of current water quality depressions are in the Cleveland Harbor near the entrance of the Cuyahoga River, and near the Westerly and Easterly wastewater treatment plants. There is considerable improvement in water quality within the Cleveland Harbor moving eastward. At the eastern end of the harbor where there is a general mixing of open lake water, the quality is surprisingly good. An additional area of water quality depression evidenced by both sediment chemistry and benthic organisms is along the lakeward side of the harbor breakwall, opposite Burke Lakefront Airport (Table 12). This area was used until recently for disposal of dredge material from the Cuyahoga River and the Cleveland Harbor.

It is unfortunate that the two public bathing beaches in the Cleveland area are located within the zones of severe water quality depression associated with the Westerly and Easterly wastewater treatment plants. These two bathing beaches, Edgewater Park and White City Beach, have been in existence since the turn of the century, and while attention has recently been called to the health hazard associated with them, the following passage indicates that the situation is not new:

> "A very proper disposal of the sewage of the City will have a very marked effect upon the quality of the water at the bathing beaches within the city limits, all of which were closed during the past year by the Board of Health. Sterilization of the effluents at least during the bathing period will render the water safe for bathing purposes.
>
> The closing of all bathing beaches means a great hardship and it seems expedient during the present season to allow the use of Gordon Park Beach (White City Beach) and Edgewater Park Beach by shutting off the nearest storm overflows." (Jackson, 1912)

The original problem at the beaches was occurring when the city had no wastewater treatment plants. When the plants were first constructed, the beach areas improved. It is anticipated that these two beach areas will again improve under the present control program. Data collection during this study will contribute to assessing the effectiveness of the presently planned program. The new Northwest Interceptor and the Westerly Wastewater Treatment Plant will provide an optimum opportunity to see improvement in the associated area of Lake Erie.

The tasks undertaken on zooplankton and phytoplankton yielded similar results in that all of these organisms were affected more by daily open lake conditions than by waste inputs from the Cleveland area. It was expected that an overall impact of the Cleveland area would be evidenced by distinct changes in the planktonic populations offshore of Cleveland as compared to populations outside the immediate Cleveland area. It was determined, however, that the plankton populations were extremely transitory and could change drastically within hours. While the populations were probably indicators of water quality conditions at some point in the lake, a detailed analysis of currents in the lake correlated exactly with water quality data concerning the impact of particular waste inputs.

Analyses of the fish populations in the Cleveland area resulted in several important findings. Although more fish species than originally anticipated were found, the more abundant of these were open lake spawners, pollution tolerant, or head-water species found in the underdeveloped areas of streams tributary to the study area. In general regard to the high number of species still found to exist in the area, it is significant that greater than 90% of all fish captured (based on numbers) were yellow perch, Perca flavescens.

Unlike benthic populations, fish species did not display any particular avoidance of particular point sources of waste input, except for the Cuyahoga River itself. With the Cuyahoga excluded from consideration, a given species of fish was equally likely to be caught anywhere along the Cleveland shoreline. At the same time, the highest concentrations of fish could be found near the significant point sources of waste input, including around the mouth of the Cuyahoga River within the harbor.

No apparent environmental stress was found relating to the size of the adult fish. It appeared that if a fish was able to pass a critical stage in growth, no effects from water quality would be evident. Yellow perch, from the Cleveland area, for example, were favorably comparable in length and weight with perch from a cleaner waters to the east and west of Cleveland. Reproduction of population recruitment was limited in the study area with respect to the overall population level of fish. Spawning was limited to the harbor, breakwall and marina areas.

Discharges of wastes from the major point sources in the Cleveland area to the lake were established. The data of most interest from the chemical monitoring program are the concentrations - total load relationships for the Cuyahoga River. Strictly on the basis of concentrations, the river showed much improvement in water quality between 1971 and 1972, for most parameters studied. However, it can be seen that for parameters studied, the total load increases with flow, even for those chemical constituents that display considerable reduction in concentration with increased river flow. This is a function of dilution from precipitation, of course, and future measurements taken to assess the water pollution control program impact will have to compare effectiveness on the basis of total load reductions rather than concentration reduction. The "improvement" seen between 1971 and 1972 in the river on the basis of concentration is in fact a reflection of the difference in rainfall between the two years; 1972 being wetter (See Figure 11). Similar statements can be applied to the Lake Erie water quality data. The conditions are distorted because of the dilution factor from higher lake levels resulting from more precipitation.

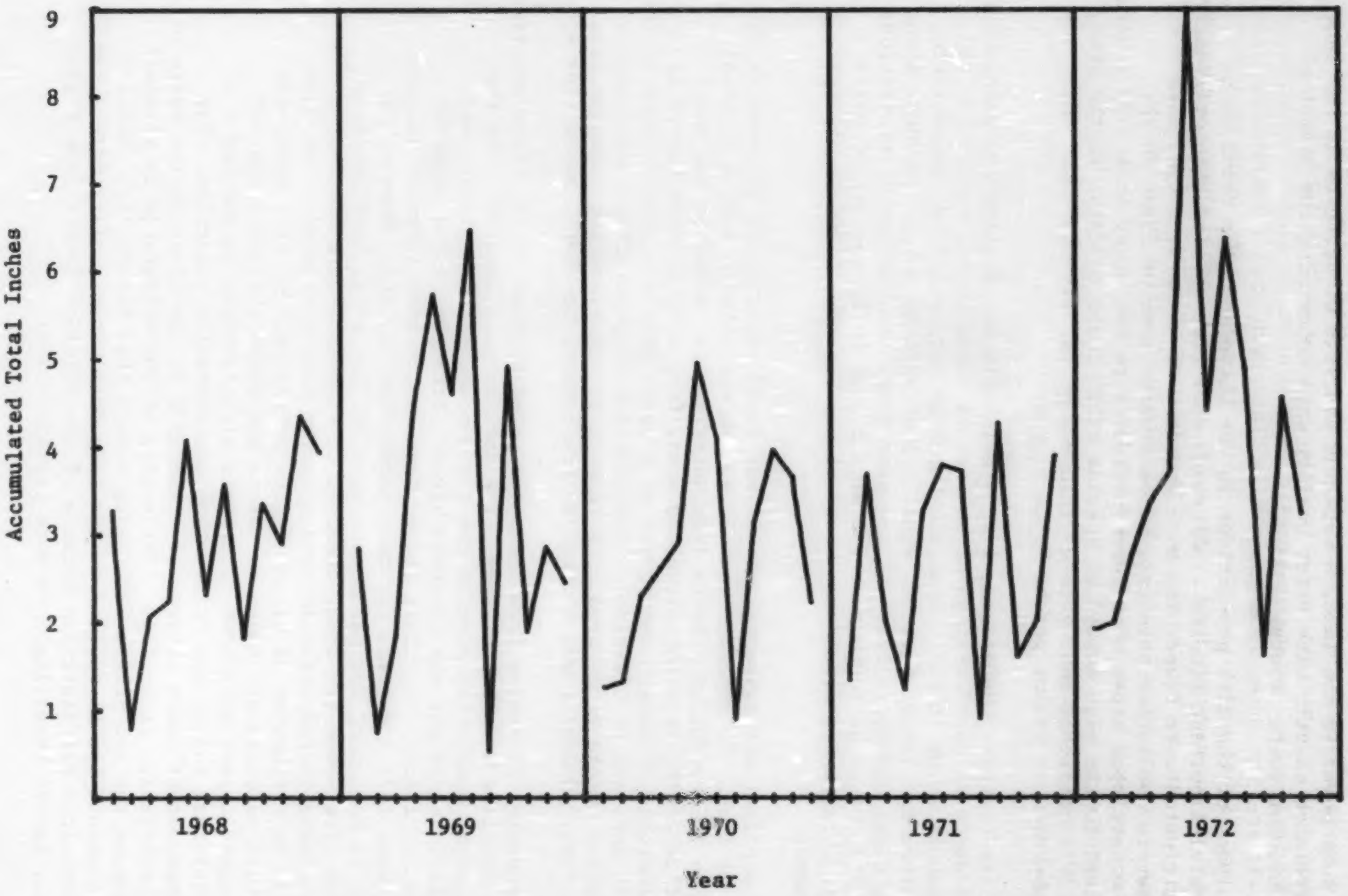
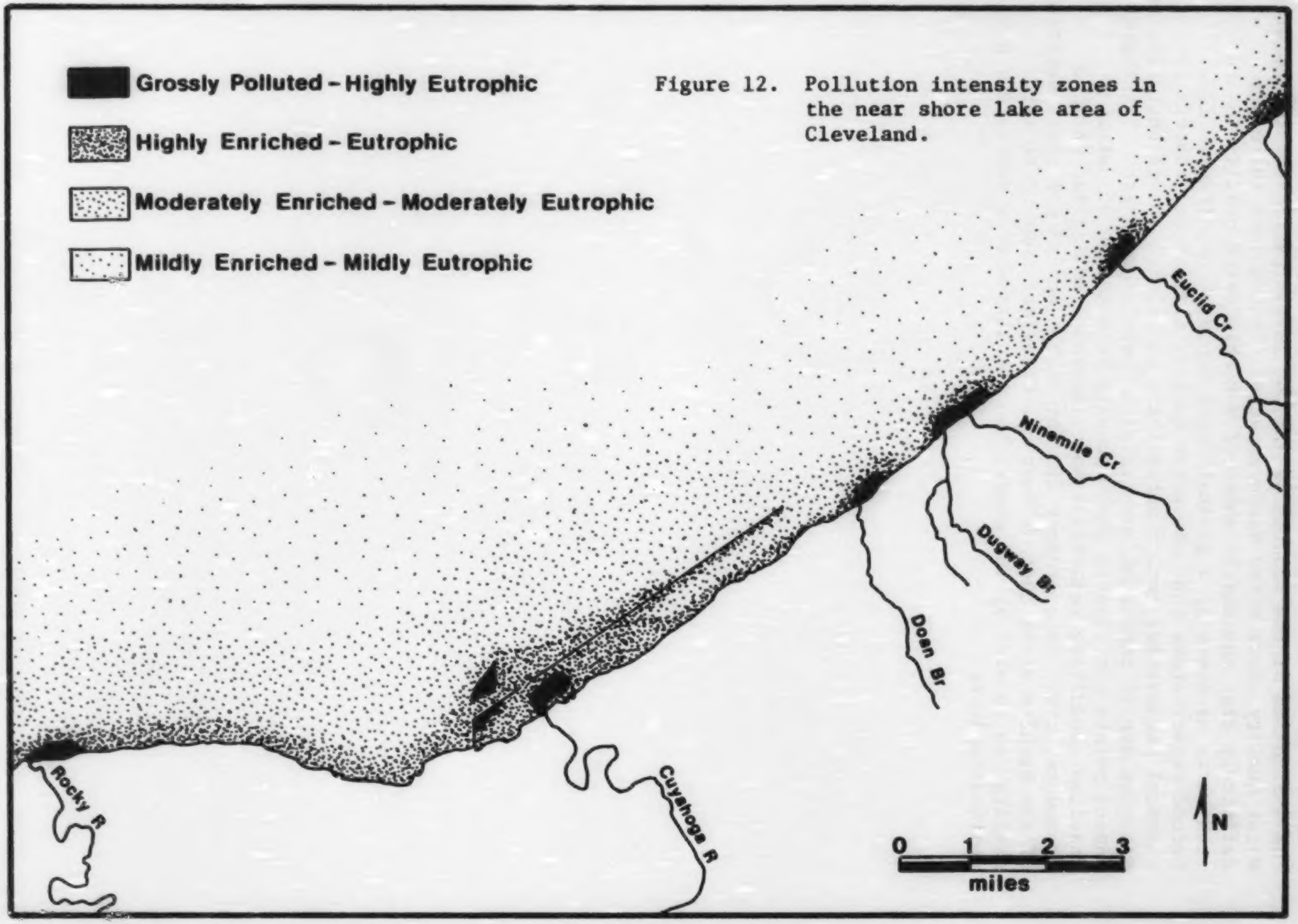


Figure 11. Total precipitation in the Cleveland area for five years (Data based on official National Weather Service statistics, Cleveland Hopkins Airport Station)

The evaluation of the results of all the investigations concerned with water quality shows three basic aspects. One is that there are definitely distinguishable zones of variable water quality in the study area as shown by a general "pollutopleth" map (Figure 12). Second aspect shows that the water quality indicators, especially chemical parameters, have a periodicity as related to concentration and dilution due to increased quantities of receiving waters. The third aspect points out clearly that accurate delineation of detailed baseline conditions requires a more intense sampling and unified framework, which this project did not have. Additional interpretation of the results shows that at best the Cleveland near shore water quality, as covered by the study, has stabilized to a depressed, but restorable level.


Grossly Polluted - Highly Eutrophic
Highly Enriched - Eutrophic
Moderately Enriched - Moderately Eutrophic
Mildly Enriched - Mildly Eutrophic
Euclid Cr
Ninemile Cr
Dugway Br
Doan Br
Cuyahoga R
Rocky R
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2
3
miles
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Figure 12. Pollution intensity zones in the near shore lake area of Cleveland.

SECTION IV

METHODOLOGY OF DATA ACQUISITION

METHODS

Introduction

The study required traditional and innovative methods of acquiring data on the past and present water quality conditions of the studied area. Each investigator conducted his own literature search, in addition to the library support project, which executed an in-depth literature survey, collected 2,154 reports, and catalogued 1,093 of the total. In relation to the methods outside literature search, accepted scientific methods were used in sample collection and analysis, according to each discipline. Most of these methods can be classed as "standard methods." The administrative methods were primarily "ad hoc" and did not constitute a systems approach. In depth descriptions of the scientific methods are contained in the appropriate indexes.

Literature Search, Compilation, and Availability

The bulk of the available literature research was accomplished through the library support project by the Sears Library specialists of Case Western Reserve University.

The aims of the library support project were: to give direct support to those working on the project, making searches and acquiring needed publications, to identify relevant literature sources, existing and on-going projects and data bases, and to study and evaluate existing thesauri to provide terms for retrieval of collected references for later retrieval by computer.

A literature specialist was employed to serve as a research librarian to the investigators and to study existing literature sources; in addition to identifying on-going projects, the data-bases which they were building, and the access to those data, including those which were computer-based. Clerical service to support the effort was also provided.

The aims of the project were carried out as follows:

First, the Lake Erie Study Collection was set up. This is a collection of reports in the environmental sciences, particularly local water pollution material. Its purpose was to serve researchers in the area of water pollution and to be the library arm of an interdisciplinary, inter-institutional project studying the pollution of Lake Erie.

The Lake Erie Study Collection started from nothing in February, 1972, and now contains 2,154 reports (1,093 of which have been catalogued), some formerly part of the Sears Library Collection, some formerly in

Government Documents, Freiberger Library, and the remainder acquired through purchase or request. 173 requests for reports were written. 100 books on the specific subject of eutrophication were selected and purchased.

This collection represents the data base planned for development as Phase I of the library project. The catalog cards prepared for this material constitute the manual record from which machine-readable records will be prepared for the automated information retrieval system planned as part of Phase II of this project.

Since February of 1972, 287 items were circulated by the Lake Erie Study Collection. These items had first to be located, procured from the issuing source, and processed.

One hundred and twenty interlibrary loans were made by the collection. These represent specific requests from project members as well as items located through a regular scanning of current bibliographies, indexes, abstracts and periodicals.

Project meetings were held at the library, at which the project members discussed their specific projects and the literature needs related to that project. The librarian described the resources and services available from the collection.

To provide a broader data base to the investigators, the water pollution literature resources at the following locations in the Cleveland area were examined:

Sears Library, Case Western Reserve University
Freiberger Library, Case Western Reserve University
Health Sciences Library, Case Western Reserve University
Municipal Reference Library, Cleveland Public Library
John Carroll University
Cleveland State University
City of Cleveland, Water Quality Program

To speed retrieval of specific sources, periodical holdings lists were collected from John Carroll University, Biology Department; Cleveland State University; and the Cleveland Natural Sciences Museum. Report holdings lists were collected from John Carroll University, Biology Department; the Water Quality Program of the City of Cleveland; and the Systems Engineering Division of the Case Western Reserve University, School of Engineering.

Secondly, to maintain awareness of research and publications on water resources at other locations, nationwide, bibliographies and directories of agencies concerned with water resources were collected. Requests were sent out to be put on the mailing lists to receive publications of relevant agencies. A file of agencies concerned with water resources was begun. This file now includes 727 agencies.

To facilitate literature searching, a record of abstracts, indexes, periodicals and bibliographies in the water resources research area was started. Systematic examination of current issues of relevant abstracts and indexes issues of pertinent abstracts and indexes was instituted. Project members were notified of reports in their area of investigation. This constituted a personalized SDI service for project members. Potentially useful reports listed in these current sources were ordered and placed in the collection.

Since currency of information is particularly important in this rapidly advancing field, a file of pamphlets and ephemers was set up. This now contains material under 150 different subject headings.

Thirdly, a search was conducted for a thesauri to provide terms for retrieval of collected references. After study and evaluation of the two United States Government water resources thesauri, as well as the abstracts and indexes in the areas of water resources, pollution and more general fields, the librarian recommended waiting for publication of the more comprehensive thesaurus being prepared by the United States Environmental Protection Agency Library. The two major reasons for the recommendation are:

1. Water pollution is inter-related with other areas of the environment. Materials covering broader areas must be included in the collection. Therefore, a thesaurus which covers a broader area must be used, supplemented by the more detailed breakdown of the water thesauri.

2. The Lake Erie Study Collection contains the publications of the Environmental Protection Agency which are received on deposit at the Government Documents Collection at Freiberger Library. This is a large, rapidly-growing collection. Concern for ease of retrieval dictates that this material should be subject analyzed in congruence with the nationwide system.

To summarize, three specific aims were set up for the library support project. The first was to give direct support to those working on the project. This was accomplished by holding project meetings, providing acquisition and interlibrary loan service, doing literature searches, and establishing the Lake Erie Study Collection, the data base for computerized retrieval in Phase II of the project.

The second aim was to identify relevant literature, projects and data bases. This was accomplished by building a collection of directories and bibliographies and establishing a comprehensive file of agencies in the water resources area. The third aim was to evaluate thesauri to provide terms for subject retrieval of literature in this area.

Chemical Methods

There were three principal chemical investigations accomplished in this project. One was the determination of buffering effects of suspended sediments on the concentrations of dissolved sodium, potassium, magnesium, and calcium in the Cuyahoga River expressed in cation exchange reactions. The second investigation dealt with the determination of chemical water quality based on dissolved solids concentration and other parameters in the Cuyahoga River and Lake Erie in the study area as shown in Figure 10. The third investigation was concerned with the determination of the chemical composition of near shore Lake Erie benthic sediments.

Cation Exchange Investigation - This investigation involved field and laboratory methods. In the field, (see Figure 10), the Cuyahoga River was sampled periodically at three sampling stations:

1. At Rockside Road bridge (approximately mile 14.8), before the river enters the major industrial area of Cleveland,
2. At the Harvard-Denison bridge (approximately mile 7.1), and
3. At the Detroit-Superior bridge (mile 1.0).

Samples were either taken from the bridges by a bucket on a line (and are therefore surface samples) or from the City's Water Quality Program boat by pumping the samples out through a hose. Most of the samples taken from the boat are triple samples obtained from three depths: a foot below the surface, a foot above the bottom and at mid depth. This method was used to test how well the dissolved ions and suspended sediments were mixed in the river. All samples from station 1 are surface because it is above the head of navigation; surface-only samples were taken at stations 2 and 3 during the winter and early spring when the City's boat was out of the water and after June 14, 1972, by which time we had concluded that the river is always so well mixed that only surface samples need be taken. The period of sampling began August 11, 1971, and terminated September 14, 1972.

In the laboratory the sediments were separated from the water either by high speed centrifugation with a Sharples centrifuge or by allowing them to flocculate from five gallons of sample. An aliquot of the water was saved for chemical analysis. The separated sediment was dried and washed with acetone and split into two aliquots for a determination of:

1. Cation exchange capacity and amounts of exchangeable sodium, potassium, magnesium and calcium on the untreated (inorganic plus organic particulate material) sample, and
2. amount of organic material oxidizable with 30% H_2O_2, the cation exchange capacity of the resulting inorganic fraction and x-ray

diffraction analysis of the inorganic fraction. Each of these procedures is described in more detail in the Bibliography.

Water Quality Chemistry Investigation - The field methods involved bucket sampling. The samples were collected from the lake or river by tossing a bucket into the stream and pouring the sample into a polyethylene sample bottle. Dissolved oxygen and temperature measurements were taken prior to pouring the sample into the sample bottle. Dissolved oxygen measurements were made with a precalibrated Yellow Springs Instrument Company oxygen meter. Samples from the sewage plant effluents were twenty-four composite samples composited hourly. These samples were brought back to the Water Quality Laboratory the same morning and they were immediately cut into aliquots and taken to various sections of the laboratory for analysis. All the analyses performed on these samples were done in accordance with Standard Methods for the Examination of Water and Wastewater, 13th edition, or, Methods for the Chemical Analysis of Water and Wastes, Environmental Protection Agency, 1971. Quality control on these samples was maintained by the simultaneous analysis of standards, duplicates, and standard addition samples.

Benthic Sediment Methodology - The samples were obtained once a month, weather permitting, at ten sites selected along about twenty miles of the southern shoreline of Lake Erie stretching from Rocky River to Euclid Creek. (Figure 10) The samples were Ponar dredge grab samples taken at the same time as other samples were taken for biological studies. The vessel used for the cruises was an open Boston whaler purchased by this grant.

The sediment samples were transferred into wide mouth polyethylene jars which had been cleaned with dichromate acid cleaning solution and rinsed thoroughly with tap, distilled and deionized water, in sequence. No preservatives were used. The jar caps were screwed on as tightly as possible to prevent access of air. Usually at least one liter of water was obtained with the sediment. Several stations had rocky or densely packed gravel bottoms so that often little sediment was obtained.

In the laboratory the samples were transferred to a cold room or refrigerator at 4° C. Usually they were allowed to stand overnight to allow the supernatants to clarify somewhat before they were decanted into 250 ml polypropylene centrifuge bottles, capped and centrifuged in a Sorval or International centrifuge at 4° C. One bottle of centrifugate was filtered through 0.45 micron millipore filters. Filtered and unfiltered water samples were analyzed as soon as possible for nitrogen, phosphorus and carbon species. Portions of some decantates were stored in plastic bottles at 4° C for possible future examination.

The sediment from which the bulk of the supernatant had been decanted was shaken and stirred with a large spatula to obtain apparent homogeneity. A portion was transferred to a Waring blender (1/2 to 2/3 full) and homogenized for one or more minutes in the cold room at 4° C. The blender was then taken to the balance room and samples were weighed out using an analytical balance while the blender was at low speed, for the following determinations.

1. Percent solids due to loss of water in drying at 70° C, in porcelain crucibles. Subsequently these samples were used to determine the percent loss on ignition and percent organic carbon.

2. Metal determinations by atomic absorption spectrophotometry.

After the above samples were weighed on the analytical balance, a 50 gram sample was weighed on a top loading balance accurate to 0.01 gram for the grease determination.

Another portion of about 100 grams was transferred to a beaker for drying at 70° C for storage.

The remainder of the blended sediment was transferred to a plastic bottle for freeze drying and storage.

If there was considerable sediment in the original gallon jar all or a portion of it was transferred to plastic jars for freeze storage in case additional investigation became desirable.

These analytical procedures were employed:

1. Percent Solids. Triplicate two to six gram samples of sediments were transferred from the Waring blender to porcelain crucibles with lids which had been weighed to constant weight on a sartorius single pan analytical balance. The samples were dried overnight in a gravity oven at 70° C, weighed and redried to constant weight. The percent solids were calculated in the usual manner.

2. Percent Loss on Ignition. (LOI) After constant weight had been attained in the percent solids determination the crucibles and lids were transferred to a muffle furnace at 900° C for at least two hours. They were cooled and weighed and reignited until constant weight was attained. The LOI was due to combustion of organic matter and loss of carbon dioxide from limestone in the sediment. The LOI was calculated on the basis of the 70° C dry weights.

3. Percent Organic Content. After constant weight had been attained after loss on ignition the contents of the crucibles were wet with deionized water. The crucibles were then placed into a large desiccator containing dry ice to provide a high concentration of carbon dioxide for absorption by the alkaline oxides and reconstitution of the corresponding carbonates. The crucibles were stored thus overnight, dried at 110° C for two to four hours and weighed. The sequence was repeated for a week

or longer until constant weights were attained. The percent carbon dioxide absorbed would represent carbonate carbon. The difference between percent LOI and percent carbon dioxide absorbed is reported as organic carbon. All calculations were based on the sediment weight after drying at 70° C.

4. Grease Determinations. Fifty-gram samples of blended sediment were weighed into 400 ml beakers and acidified to ph less than two with one to two ml of six normal sulfuric acid. Fifty grams of anhydrous magnesium sulfate was stirred into the sediment and spread on the sides of the beaker. Mixing was continued intermittently until the mixture dried. The dried mixture was ground with a mortar and pestle and small Wiley mill if necessary until all the material passed thirty mesh. Two 40 gram portions were weighed into a medium sized Soxhlet thimble and set up for extraction with redistilled hexane. The Soxhlet extraction apparatus was set up and the heaters were controlled with a Variac transformer to carry out the extraction at 20 cycles per hour for four hours. At the end of the extraction period the extraction flask was attached to a Rotovap for removal of the hexane under reduced pressure. The concentrated extract was filtered with suction through a small medium porosity fritted funnel into a preweighed 10 ml erlenmeyer flask or vial. The extraction flask was rinsed several times with hexane using a Pasteur transfer pipet. The hexane was evaporated from the 10 ml receiver by drawing air through the funnel in situ. The 10 ml vessel with grease concentrate was dried in a vacuum oven at room temperature overnight before being weighed on the analytical balance. The percent grease was calculated on the basis of the percent solids in the 20 gram portion of wet sediment per sample.

During the course of the project the Soxhlet hot plate burned out so that sediment samples had to be stockpiled until a new hot plate was available. It was decided to use 20 gram portions of sediment which had been dried at 70° C or freeze dried. No magnesium sulfate was required during the extraction of such samples.

5. Heavy Metals Determination. Triplicate samples of blended sediment weighing two to eight grams were weighed into small preweighed Soxhlet thimbles which absorbed the water. The thimbles were placed into 200 or 250 ml erlenmeyer flasks with 29/40 ground glass necks so that reflux condensers could be attached. The samples were treated with 80 ml aqua regia to decompose the paper thimbles and dissolve as much of the sediment as possible. The samples were digested under reflux overnight. The condensers were rinsed into the flasks with deionized water and diluted solution was filtered through Whatman 42 filter paper into 500 ml volumetric flasks. The residues were washed thoroughly with deionized water and the filtrate was made up to 500 mls. The filtrate was transferred to one pint plastic bottles for storage. The filtrate was less than two formal in total acid because of decomposition of aqua regia during digestion.

The metals were determined on the filtrate, diluted if necessary, by atomic absorption spectrophotometry with an Instrument Laboratory 153 Atomic Absorption Spectrophotometer. The metals analyzed were cadmium, calcium (with lanthanum chloride diluent added), chromium, cobalt, copper, iron, lead, mercury (flameless atomic absorption spectrophotometry), nickel and zinc. The results were reported as milligrams per gram dry sediment based upon standardization curves for each element.

6. Total Nitrogen (Kjeldahl) in Sediments. Two hundred milligram samples of sediment which had been oven dried at 70° C or freeze dried and pulverized to pass 100 mesh were weighed and transferred into 100 ml micro-Kjeldahl flasks and digested in concentrated sulfuric acid, potassium sulfate and mercuric sulfate in the usual manner until white fumes of sulfur trioxide were obtained and the solution was colorless or pale yellow. The residue was cooled, diluted with deionized water and transferred to the reaction flask of the micro-Kjeldahl distillation apparatus. The solution was made alkaline with sodium hydroxide-sodium thiosulfate solution and heated to distill the ammonia into a calibrated beaker containing 10 ml of two percent weight per volume boric acid solution until the 50 ml mark was reached. The absorbed ammonia was titrated with 0.02 normal HCl using a microburet.

7. Total Phosphate in Sediments. The total phosphate was determined on the dilute aqua regia solution prepared for heavy metal analysis. Due to the high iron content of the solutions it was necessary to use the benzene-isobutanol extraction procedure followed by stannous chloride reduction. (223 Method E, Stannous Chloride Method, Standard Methods, 13th Edition, pp 530-532)

8. Carbon Species in Aqueous Supernatants. Organic carbon and carbonate carbon were determined on filtered (0.45 micron) and unfiltered supernatants. The Labconco Micro-Kjeldahl apparatus was used for ammonia- and Kjeldahl- nitrogen analyses, the liberated ammonia being determined titritmetrically using a microburet. Nitrate-nitrogen procedure was the cadmium reduction sulfanilic acid - napthylamine method using the Hach Nitraver IV combined reagents pillows. The color developed was read at 520 nanameters with a Beckman DU spectrophotometer. The nitrate method was the sulfanilic acid-napththyl amine procedure with Hach Nitriver pillows. The color was read at 520 nanameters as in the nitrate test.

9. pH Values of Aqueous Supernatants. pH values were measured at room temperature on filtered (0.45 microns) and unfiltered supernatants using a Sargent pH meter, Model LS.

10. Conductance Values of Aqueous Supernatants. Conductance values were measured at room temperature on filtered (0.45 microns) and unfiltered supernatants using a Yellow Springs Instrument Conductivity Bridge Model 31.

Biological System Related

There were basically five major areas of investigation related to biological systems. One was the investigation of Cladophora sp. green algae occurrence in the study area. Second area was the phytoplankton occurrence and distribution. The third principal investigation concerned itself with zooplankton occurrence and distribution. The fourth investigation was the benthos occurrence. The fifth dealt with fish populations in the study area.

Cladophora - This investigation collected two sets of algae using two basic methods in field sampling and laboratory investigations. The first were made during August and September of 1971. Collections were from selected sites spanning most of the extent of shoreline included in this study.

Samples were taken by placing a metal cylinder, open at both ends, over the plants to be sampled. The cylinder was held firmly in place while all plant material immediately surrounding the cylinder was cut and scraped away. The cylinder was then removed and the circle of isolated plant material was quickly and carefully scraped from the substrate and placed in a sealed plastic container. Sharpened putty knives were used. Common food cans, with both ends removed, were found to be convenient and easily replaced "metal cylinders".

The plastic containers holding the samples were placed in an ice-chest for transportation to the laboratory where they were stored at 4° C. In most cases, the samples were stored no more than 24 hours.

The samples were filtered in a Buchner funnel and collected on Whatman number 1 filter paper which had been dried at 60° C and pre-weighed. The samples were dried at 60° C to constant weight. The data are reported as dry weight per square centimeter of substrate.

Samples were taken from rocks at the nominal surface of the water. Dislodging and removing a sample between waves required quick action and good timing. Collection in this manner is impossible in wave conditions exceeding one foot height.

The second set and methods were designed and used because the 1971 work showed that sampling natural substrates would yield limited information, showing no valid relationships between water quality and Cladophora growth. The new sampling program for 1972 was based on samples from uniform artificial substrates.

The Cladophora traps used consisted of one-inch thick pine boards twelve inches square, coated with epoxy resin with a sheet of fiberglass on one surface. The fiberglass was applied to provide a rough surface on one side to compare with the glass-smooth epoxy surface on the other side. The traps were anchored to 45 pound concrete blocks with quarter-inch diameter braided nylon rope. The depth of water varied from three to five meters at the different sites. The anchor ropes were cut so that the traps floated in a vertical position with their tops a few centimeters below the surface. Small styrofoam floats were attached to the traps with about two meters of light nylon line to aid in locating the traps. This method of anchoring and buoying the traps worked well. Most of them were recovered. However, many of the buoys were lost and at least half of the traps were broken by power boat propellers. All data reported for 1972 are from these traps. Prior to developing this method of anchoring and buoying the traps, many were lost. Hurricane Agnes destroyed or removed all the traps which had been set out in June of 1972.

Phytoplankton - A study of comparative phytoplankton populations at several stations along the Cleveland area waterfront was performed during 1972 (See Figure 10.). Samples were collected from each thirteen stations once a month. A fourteenth station was sampled sporadically. Samples were collected quantitatively in three replicates, fixed with acetic IKI and the phytoplankton enumerated using Untermohl chambers.

The gross numbers of phytoplankton were converted to biomass and reported as cubic microns per liter. Comparisons were made between monthly averages of biomass of all stations and comparisons of single stations on a monthly basis.

Zooplankton and Benthos - Ten sites along the Cleveland lake front and three sites located further out in Lake Erie were sampled regularly for zooplankton and benthos from September, 1971, to November, 1972. Zooplankton were collected with a vertical tow net while benthos was collected with a Ponar grab sampler. Samples were preserved in five percent buffered formalin and processed in the laboratory. Along with zooplankton and benthos, water temperature, dissolved oxygen, specific conductivity, and pH were measured at each site.

In the laboratory, the zooplankton was split several times and subsampled. The zooplankton was then counted and identified using various zooplankton keys. Benthos samples were segregated by sieving through a U. S. number 30 soil sieve and then hand-picked from the residue. Oligochaetes were subsampled, when large numbers occurred using a tray with a grid pattern and randomly sampling the grids. Dry-weight biomass was obtained for the oligochaetes by drying to constant weight at 60° C and then incinerating at 600° C. Cherinomid larva identification was made using head slides. All benthos was identified using various invertebrate keys. Data was analyzed using Fortran IV computer programs for species diversity indices, diversity equitability components, and community similarity coefficients. For sampling locations refer to Figure 10.

Fish Populations - The methods used in fish studies are detailed in Volume II. The same study area applies to this investigation as shown in Figure 10. The field collections were conducted in the nearshore areas of Lake Erie, and in the drainages of the Rocky, Chagrin and Cuyahoga systems. During the period of June 1, 1971, through December 31, 1972, more than 200 collections were made at various sites, some of which were sampled repeatedly.

Samples were taken in deeper waters employing an 18½ foot outboard motorboat or a rowboat. During periods of heavy seas a chartered commercial fishing vessel was used. In order to insure that the greatest variety of fishes were collected, several sampling methods were utilized, depending upon the conditions of the sample sites. These methods are common methods used for fishing. Experimental gill nets were used to sample in the open lake, the deeper portions near shore, and the lower sections of the river drainages. These nets were 125 feet in length, six feet in depth, and consisted of five panels of varied stretch mesh sizes (one inch, one and one half inch, two inch, three inch, four inch).

Stations were sampled with experimental gill nets for periods of twenty four to forty eight hours. In some cases additional gill nets were utilized, these having stretch mesh sizes of two, two and three fourths, three, eight, ten, or twelve inch stretch. The gill nets were set between zero and seven feet from the bottom, and at least ten feet below the surface. Trawling samples were taken in an attempt to capture species that were either too small to collect with gill nets or that were not readily taken by the gill net. The trawl utilized in the collection of this data was a sixteen foot semi-balloon otter trawl equipped with mud rollers.

Rivers and shallow beaches along the shoreline were collected by seining. Depending upon the characteristics of the sample site, a variety of seines were utilized. These included:

1. A 50 ft, ½ inch mesh seine with a 4 x 4 ft bag.
2. A 26 ft, ¼ inch mesh seine with a 4 x 4 ft bag.
3. A 16 ft, ¼ inch mesh seine with a 4 x 4 ft bag.
4. A 8 ft Common Sense Seine, 4 ft in depth.
5. A 8 x 4 ft fry net with 1/16 inch mesh for sampling fish fry in streams and/or beaches.

Seining was accomplished by utilizing three-man crews and sampling all available habitats within a one half mile area of the station. Of the fishes collected, approximately 95% were identified to species and returned to the stream, with the exception of representative specimens which were preserved in six percent formalin and returned to the laboratory for confirmation.

Fyke nets were utilized on a limited basis due to the heavy use of the study area by recreational boaters and sport fishermen. No attempt was made to actively survey the catch of either sport or commercial fishing. However, certain species of fishes were observed and reported only by persons engaged in these activities. These reports have been considered valid only when they were substantiated by either the specimen or a dated, clear photograph. Such information has been included in the distribution reports and in the current status discussion. In addition, the records of both the commercial catch and the Ohio Division of Wildlife gill net survey have been accepted as valid and utilized as a source of data.

Observations of fishes without supporting collections were in most cases considered invalid. Only the observation of a species having unique identifying characteristics were accepted and then only if reported by a reliable observer. Such species as gar were accepted, while species such as the emerald shiner, blue gill or white sucker were not accpeted unless substantiated by a specimen.

Utilizing all of the above methods, approximately 77,000 specimens of fishes were captured and examined. All except about 7,000 of these were subsequently released. These latter specimens are currently preserved in the museums of John Carroll University and the Ohio State University and will be maintained for future documentation and/or research.

METHOD EVALUATION

Most of the methods employed in the investigations were acceptable standard procedures. The reproducibility and accuracy of the results depend primarily on the individual analyst. One of the most glaring deficiencies in the field study aspects of the program was the low sampling frequency. A sampling frequency of sixteen days per year is too low to establish short term fluctuations in water chemistry, changes in biota, and other related changes such as diffusion, currents, etc. Methods used in each principal area of investigation are critiqued.

The cation exchange reaction investigation neglected the volume and flow rate of the river at the time for the sampling, ignoring the dilution effects of variable volumes and flows.

The benthic sediment investigation exhibits several areas of deficiency. In the sampling procedure information such as temperature, dissolved oxygen, current direction and velocity should have been obtained to obtain a detailed framework of the water chemistry. Thickness of the sludge deposits should have been calculated, and the entire sampling program should have been coordinated with sampling and analysis of the surface water to reduce variability in time and space. There is a question whether the in situ chemistry of the sediments was maintained during the transport and preparation of samples. In the laboratory chemical calculations should have been based on dry solids rather than wet sediment, due to lack of control of the moisture content in the sediments. The results can not be used for determining heavy metal pollution effects, because no heavy metal background concentration analysis was attempted to establish natural baseline.

The methods employed in collecting and measuring phytoplankton are reliable and reproducible. The identification of organisms however, appeared to be limited to the easily recognized and major forms. If comparisons of changes in populations in the future are to be made it will be necessary to know more exactly which species or at least genera are present or predominant during different periods of the year. Since only a few of the forms were identified to even the genera level, it was impossible to apply any indices of population or community structure to the phytoplankton. Such indices could describe changes in dominance, or equitably from which a predictive pattern could evolve.

While this study was intended to provide baseline data on current water quality conditions, there were insufficient samples taken to fully delineate changes in phytoplankton density with respect to either time or pollution inputs to the Cleveland area waterfront. In order to fully gather the required baseline data, it would be necessary to sample more frequently and perhaps on a more limited area basis. In order to determine effects of inputs upon the biota in general, we should first know the flow and dispersal patterns of the inputs upon then establish sampling locations on a definite grid basis.

The zooplankton and benthos study like the other investigations had a low sampling frequency. The methods used in this study were appropriate and acceptable for the problem at hand. Some of the methods tend to have inherent sources of error which must be considered. One method, calculation of the species diversity, requires that harsh environments have few species with abundant population while favorable environments have many species none of which are greatly abundant. This assumption is somewhat weak, because low species diversity does not mean that the environment is necessarily unfavorable. The low diversity could indicate that organisms have not colonized a favorable environment because they simply are not in a close enough proximity to invade this area. One of the methods used in this study, ordination analysis, as applied to water pollution biology, is a valid technique. Using this procedure a number of environmental gradients can be compared with respect to various communities.

The administrative methods of managing the project were "ad hoc." The magnitude of the project mandated a systems approach, which was not utilized. Project management techniques such as PERT - CRITICAL PATH or other applicable methods would have aided in establishing a framework for target dates, personnel, communication flow, fiscal control, and priorities. The design of a water quality baseline assessment model would have given a useful tool for an organized and systematic execution of this phase of the program. This model could be a submodel of a large comprehensive model of the entire three phase program. Such a model has predictive capabilities incorporated into its design, and can be used to evaluate economic and technical feasibility and predict ecosystem response to remedial measures.

SECTION V

STUDY RESULTS AND DISCUSSION

RESULTS

Background

The individual investigations produced results that have to be integrated into a total framework. The investigations had a biological and chemical orientation, and did not assess the physical system. To establish a meaningful synthesis of the results, the total environmental system must be considered. The total environmental system is made up of physical systems that largely determine the existence and nature of the biological life. Only when the study area is assessed through an ecosystem perspective, can the proper ecological baselines be established for departure in assessment of water pollution control and water quality management programs.

Physical System

The physical system requires knowledge in a number of specialized areas. In relation to water quality assessment and management the critical areas are geology, topography, geomorphology, hydrology, hydrogeology, currents, drainage patterns, erosion potentials, land use, climatology, meteorology, and other areas. The delineation of the physical environment establishes natural sources of pollution and their magnitudes, and shows the path and impact of the man-generated pollutants in the environment. This study did not incorporate a comprehensive assessment of the physical environment, apart from the hydrodynamic modeling, and very specialized chemical investigations. The following discussion of the physical environment is presented to correct the deficiency. It is based on literature research, and on field observations and studies.

The study area is located on the southern shore of Lake Erie, which is part of the Great Lakes-Saint Lawrence River drainage basin. Climatological data for the City of Cleveland (National Weather Service, 1972) shows that the climate is continental in character and strongly influenced by the lake as a temperature and moisture moderator. Annual normal average temperature is 50° F, with about 70 freezes and thaws per year. Precipitation averages 36 total inches per year. The evaporation rates for the lake average also 36 total inches per year showing the dependence of the lake levels on the flow from upper Great Lakes, fluctuating runoff, and groundwater influx. The number of freezes and thaws indicates that frost heaving is a significant erosional agent in the area, especially in destabilizing the Lake Erie shoreline.

The prevailing winds are from the southwest, but they show seasonal variations. The predominant winds occur along a southwest-northeast axis. The yearly mean wind velocity is eleven miles per hour. Generally, local topographic variations exert very little influence on the overall climate, apart from Lake Erie, which is the principal climatic modifier.

The macro-phytosociology of the study area shows that the original plant communities consisted of four main types of plant associations (Gordon, 1969). In decreasing aerial extent, these were beech forests, mixed oak forests, mixed mesophytic forests, and elm-ash swamp forests. The relative distribution of each association was primarily influenced by local climate, drainage, and geologic conditions as related to surficial deposits. As pointed out in the introduction of this report, the agricultural practices, urban land use, and denudation of land were the initial steps that resulted in the degradation of the aquatic environment in the study area. The original vegetative patterns prevented excessive erosion and siltation of the rivers and the lake. The physical modifications of the surface cover and draining and filling of marshes, destroyed fish breeding areas and the associated complex biological ecosystems.

The geology of the study area illustrates a non-catastrophic evolution of the present landscape. The consolidated rocks underlying the region are composed entirely of sedimentary materials, shales and sandstones being predominant in the study area. The strata dips basically southeast with local variations. A close agreement exists between the surface relief and aerial location of the sedimentary bedrock surface. The consolidated strata are blanketed by glacial deposits left by the ice sheets, which once covered the area. The action of the ice masses were very influential in shaping the present physiography, although the net effect of this action has been greatly masked by the sediments deposited as the glaciers retreated (Cushing, Leveret, Van Horn, 1931).

The materials left by the glaciers consist mainly of tills (southern portions of the study area), and glacial cave sediments (northern portions). Two low moraine ridges also occur in the area, one in the central western section trending roughly west to east across the Cuyahoga River, and, the other in the northeastern section, trending west to northwest across the Chagrin River. Low elongate sand ridges occur predominately in the northern section, roughly parallel to the present Lake Erie shoreline. These deposits represent former glacial lake beaches (Cushing, Leverett, Van Horn, 1931).

Physiographically the area may be divided into three definable regions. The lines dividing these sections trend roughly northeast across the study area, and are strongly distorted by local drainage patterns. The south section belongs to the Appalachian plateau region. The topographic character of this area can be described as hilly to rolling. Trending northeast across the region is a two to four mile wide slope, known as the Portage Escarpment. It is irregular and discontinuous because of the stream valleys cutting across. The major portion of the escarpment is composed of shale. The slope is fairly uniform with a 40 to 80 feet per mile gradient present. The escarpment defines the line separating the remaining section, Erie Plain, from the Appalachian Plateau. The Erie Plain occupies the north and large part of the eastern sections of the study area. A considerable part of it is submerged under the waters of Lake Erie. The topography of this area is relatively smooth and has a lakeward slope of about 50 to 60 feet per mile (Cushing, Leverett, Van Horn, 1931).

The drainage system of the region is strongly modified as it flows across these three sections. The smaller streams which have their headwaters in the plateau flow north towards Lake Erie. As they pass over the escarpment, many have incised deep valleys into the underlying soft shale. Once they reach the Erie Plain, the streams flow in shallow valleys with decreased velocities. Concurrently, the streambeds change in character, being composed of glacial-lake silts and clays. The three major drainage systems, the Cuyahoga, Chagrin, and Rocky rivers, all originate outside of the south of the study area. Due to their greater volumes, they have cut deeper and narrower valleys through the underlying glacial sediments and bedrock, than the smaller rivers. Average flows and total drainage areas for these three major rivers are: Rocky River, 294 square miles, 278 cubic feet per second (CFS); Cuyahoga River, 813 square miles, 862 CFS; Chagrin River, 267 square miles, 336 CFS (Ohio Division of Geological Survey, 1966).

The soils of the area are strongly related to the parent material, the previously described glacial deposits. They generally can be classed as imperfectly to well drained, fine grained soils, predominantly calcareous and slightly acidic (Division of Lands and Soils, 1960).

Due to the relatively high sediment loads, the major drainage systems require dredging in the navigable portions. Table 12 shows the various materials and quantities dredged annually from the Cuyahoga River and the Cleveland Harbor. Much of the sedimentation is a result of erosion from improperly managed urban and rural lands, and disturbed river banks. Siltation combined with industrial chemical discharges are major problems in toxic sediment conditions in major drainage systems, especially in the navigable portion of the Cuyahoga River. Apart from some organic contributions, the background natural water pollution is insignificant in the study area except in swampy and marshy areas.

The three major river systems drain into the portion of Lake Erie covered in the study. The shoreline of the study area exhibits steep cliffs and small beaches composed generally of gravels. Local variations exist such as Edgewater Park, Gordon Park and White City Beach. The nearshore bottom is generally composed of sands, gravels and clay with the exception of the area west of Edgewater Park which is bedrock shale.

Local variations of bottom topography are common but significant features such as former valleys are difficult to distinguish, because

Table 12. LOADINGS TO LAKE ERIE FROM CLEVELAND HARBOR AND RIVER DREDGING JULY 1, 1966 TO JULY 1, 1967 (quantity in tons)

Constituent	From River	From Harbor	Total
COD	110,000	19,000	129,000
BOD_5	7,100	1,000	8,100
Chlorine Demand (15 minutes)	14,000	2,400	16,400
Volatile Solids	58,000	13,000	71,400
Oil and Grease	16,000	1,600	17,600
Phosphorus	1,860	300	2,160
Nitrogen	2,300	320	2,620
Iron	51,000	9,000	60,000
Silica	270,000	140,000	410,000
Total Dry Solids	460,000	200,000	660,000

they have been filled by sediments. The formation of deltas is impeded both by natural and man-made factors. The longshore current, which trends southwest to northeast, removes most of the river-borne sediments. Dredging for shipping lanes is the other major factor that prevents the formation of deltas.

There are two main divisions of the longshore current. The first is the surface current whose direction varies with the direction and strength of the wind. The second is the subsurface current which trends southwest to northeast irregardless of wind or other factors. Locally, each of the three rivers has a strong effect on the quality of the lake waters. Overall, the effect is present but diminished by the dilution effect of the lake. Seiches do not affect water quality to a great degree due to the fact that in the Cleveland area a seiche is present about 95% of the time.

Most of the rivers, especially the Cuyahoga River, act like estuaries due to the varying lake conditions. Cuyhaoga River can be observed flowing backward in the navigable portion. Based on the predominantly easterly littoral drift and longshore currents, the polluted discharges from point sources on land and stream discharges due to greater density tend to be in part confined and carried along the shore. Although dilution of the polluted discharges occurs, the dilution itself is insufficient to "homogenize" the waters in terms of water quality. The "pollution zones" shown in Figure 12, are primarily a function of the physical characteristics of the near shore currents and of the shoreline.

The hydrodynamics investigation was conducted by Drs. Wilbert Lick and Joseph Prahl of Case Western Reserve University, who attempted to predict and describe the hydrodynamic behavior of the Cuyahoga River entering the Lake and thermal discharges from future nuclear power plants to be located on Lake Erie. Numerical and experimental models with limited field verification were developed. The most important part of the investigation dealt with the hydrodynamic modeling of the Cuyahoga River discharge. A brief summary of their study is presented.

The modeling attempted to develop capability to predict the diffusion of the polluted discharge of the Cuyahoga River into the Cleveland Harbor and the open Lake. The model dealt with the mass, momentum and energy flow.

The numerical model was developed for a time-dependent, three dimensional, variable density, variable temperature flow of a rectangular jet horizontally entering a basin of semi-infinite extent. The results were based on steady state conditions, comparing the heated, constant temperature, and cooled jets for conditions similar to those which would be typical for the Cuyahoga River entering Lake Erie in the late summer months.

The experimental model was developed using a 20 ft. by 6 ft. by 6 in. water table with end and side jets. Experimentation was performed with non-buoyant jets with and without cross-flows. The measurements were made for a range of jet Reynolds numbers, jet width-to-depth ratios, Fronde numbers, water depth, table width-to-jet width rations, and cross-flows. A comparison of the numerical and experimental models showed qualitative agreement. Limited field verification and comaprison to previous work done on the Cleveland Harbor and Cuyahoga River flows by Havens and Emerson, Ltd. (1968) showed similar qualitative agreement.

The Cuyahoga River discharge model with bottom friction and no cross-flow is shown in Figure 13. This model assumes that no mixing occurs due to wind driven Lake currents or buoyance effects. The model is based on actual dimensions of the Cuyahoga River of 61 meter width and 9 meter depth. The model shows that at about ten river widths, roughly 640 meters from the shore, the centerline velocity of the River is about 70% of the entrance value, while the half width is about three times the entrance value, roughly 180 meters. Under these conditions with the dimensions given, it is evident that the River discharge maintains its physical identity for an appreciable distance from the entrance. This dimensional development is more likely to apply during spring conditions when the flow rate is high. During low flow conditions in the summer when the flow may be a magnitude smaller, the development of the plume is more rapid due to buoyance and bottom friction. This has been, in part, verified by aerial photographs.

The model of the Cuyahoga River discharge with cross-flow and bottom friction was developed to predict the behavior of the discharge with lake current outside the breakwall and a current inside the breakwall.

The first case (Figure 14) predicts, neglecting buoyance and with the absence of a current inside the breakwall, that the River is only moderately deflected by the lake current. These conditions are based on an average River discharge of 1700 liters/second, an average velocity of 4.5 cm/second, characterized by symbol $\bar{q}_o$, a lake current of magnitude $\bar{u}_c = 0.135\ \bar{q}_o$, and with a river discharge velocity of 75% of its initial velocity.

The second case assumes a current behind the breakwall equal to the lake current. This current is assumed to be caused by the lake current flow through the opening in the breakwall at the west end of the Harbor, the Edgewater Yacht Basin. Experimental modeling and aerial photographs show that even small currents inside the breakwall deflect the River discharge before it reaches the breakwall opening into the lake (Figure 15).

Although these models neglect buoyance effects, the qualitative results describe the real conditions. When the buoyance factor is considered, the River mass is expected to float to the surface thereby decreasing bottom friction effects. This would result in a decrease in the River deflection.

Previous studies (Havens and Emerson Ltd., 1968) showed that about 80%

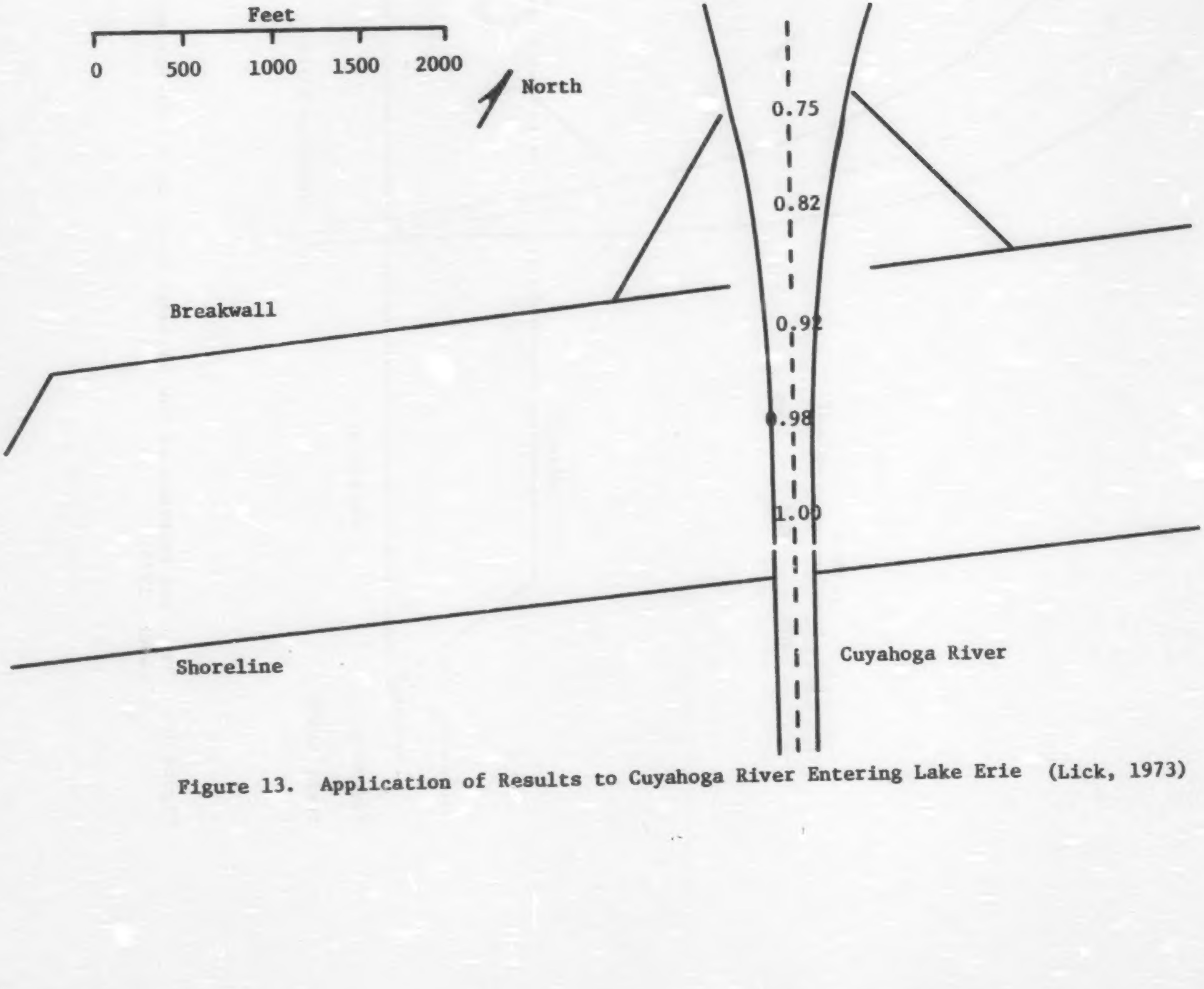

Feet
0
500
1000
1500
2000
North
0.75
0.82
0.92
0.98
1.00
Breakwall
Shoreline
Cuyahoga River

Figure 13. Application of Results to Cuyahoga River Entering Lake Erie (Lick, 1973)

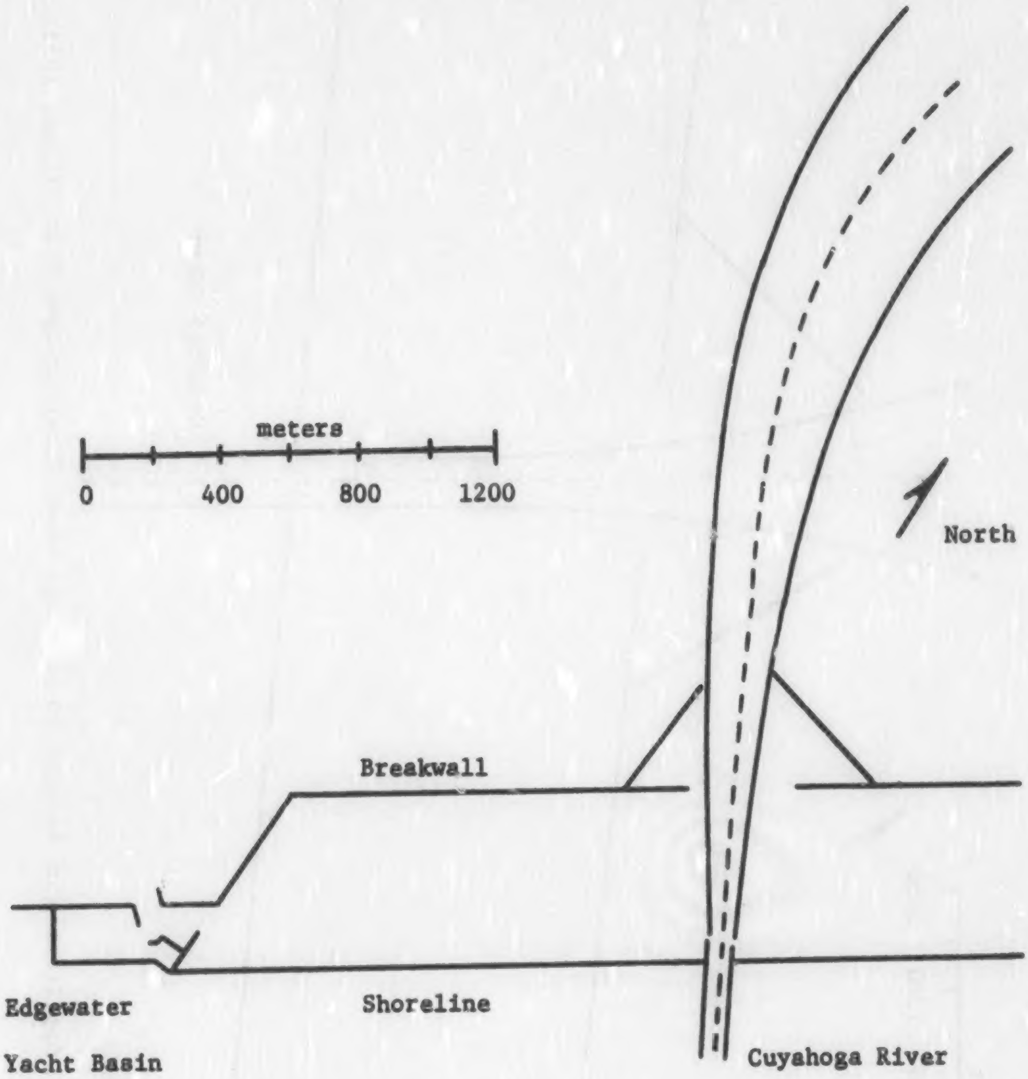

meters
0
400
800
1200
North
Breakwall
Edgewater
Yacht Basin
Shoreline
Cuyahoga River

Figure 14. Predicted response of the Cuyahoga River to a lake current. (Lick, 1973)

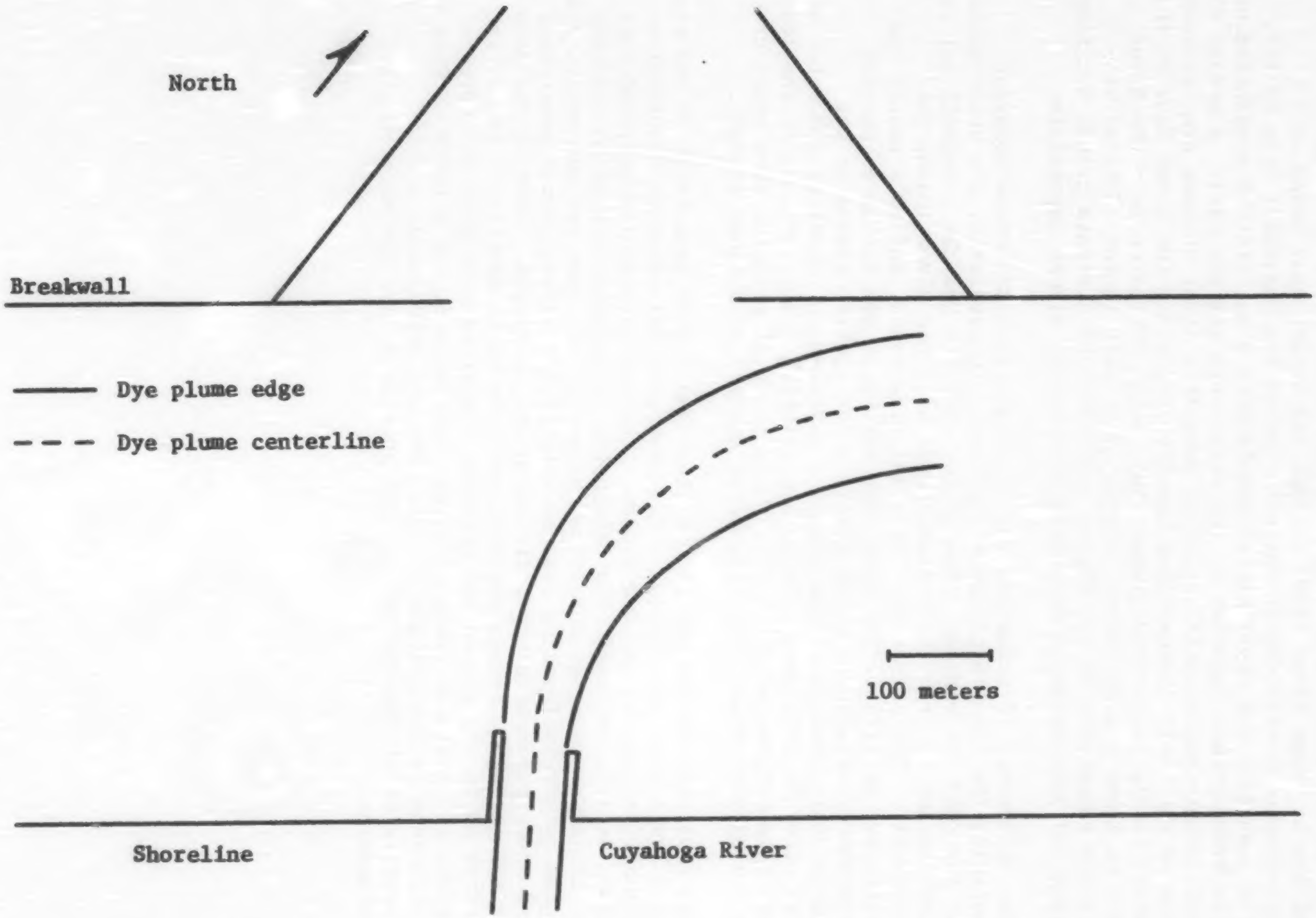
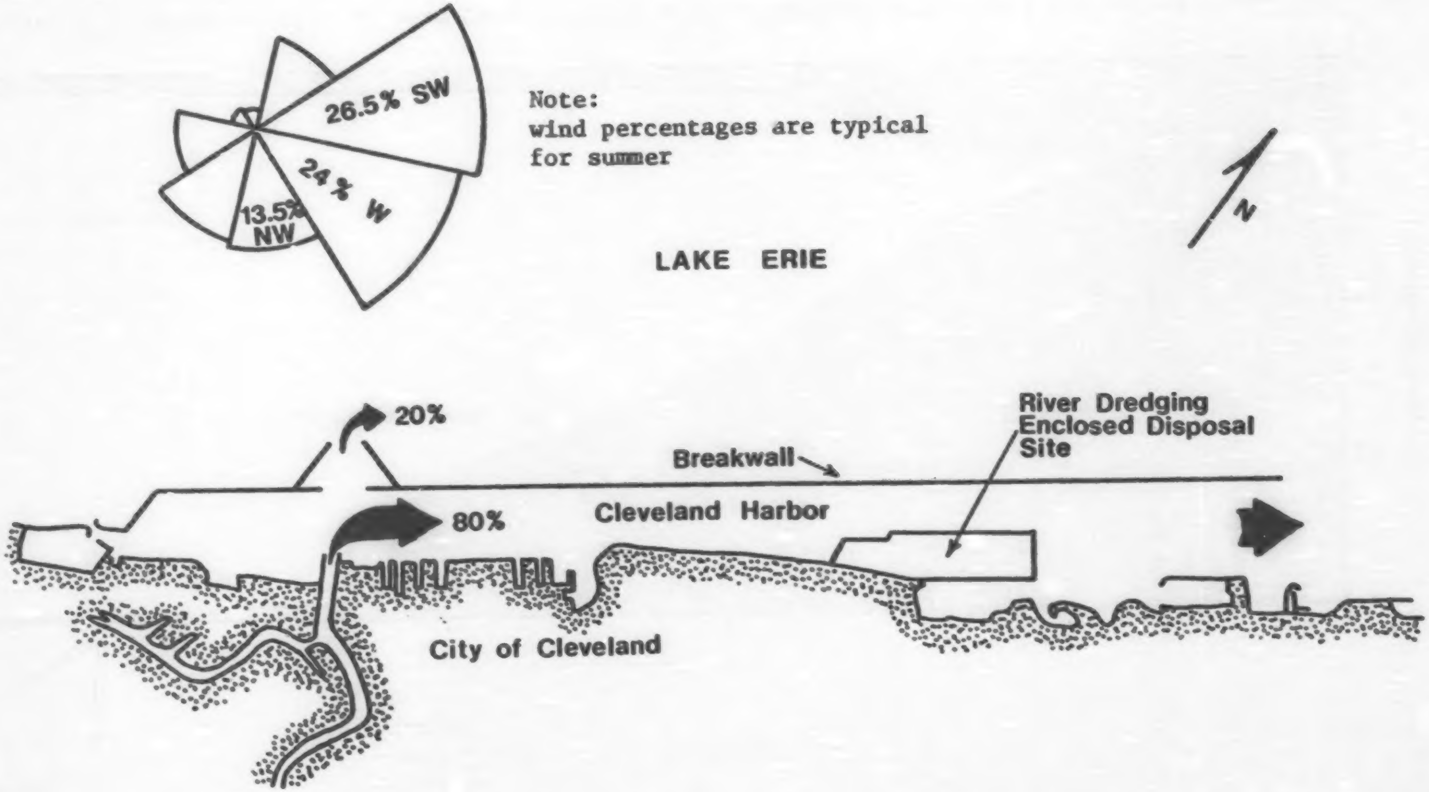

North
Breakwall
Dye plume edge
Dye plume centerline
100 meters
Shoreline
Cuyahoga River

Figure 15. Predicted response of the Cuyahoga River to a current behind the breakwall. (Lick, 1973)

of the Cuyahoga River flows through the Harbor east based on the occurrence of wind driven currents inside the breakwall (Figure 16). The numerical and experimental models give a qualitative prediction of the hydrodynamic behavior of the River entering the Lake. A number of refinements and quantification of data from field studies are necessary. One of the basic factors that heavily influences the River flow at the mouth is the constantly present lake water intrusion into the River for at least a mile inland (Figure 17). This factor combined with bottom topography in the highly variable lake currents create a mixing zone and make accurate mathematical modeling almost impossible.

The importance of assessing the Cuyahoga River discharge behavior entering the Lake is of great importance in predicting the water quality in the near shore areas. The Harbor currents and the breakwall act in combination to trap the polluted stream of the River inside the breakwall. The Harbor acts as a settling basin, and as a result the diffusive ability of the open lake waters is not utilized creating nearshore pollution. No realistic water quality standards are applicable, because of the changing physical and chemical character of the water in this area. These conditions are also evident in the lowest one mile portion of the River, where the well aeriated lake water creates a mixing zone where different water quality conditions prevail.

The physical environment of the Cleveland region as covered by the study, is a low energy environment. The many past and existing combinations of climate, rocks, soils, vegetation, agricultural development, and many human activities impair the recognition and prediction of the effects on Cleveland water quality from changes in the land use and modification. These interrelationships must be established before proper assessment and sound predictive capabilities can be developed. Much of the data on the Cleveland region physical environment is available, but it is scattered in literature and agencies concerned with geology, meteorology, hydrology, soil and plant sciences, agriculture, and forestry. Only a comprehensive integration of this data can bring about a full description of the environment and provide a base for water quality management.


26.5% SW
24 % W
13.5% NW
N
LAKE ERIE
20%
80%
Breakwall
River Dredging Enclosed Disposal Site
Cleveland Harbor
City of Cleveland

Note:
wind percentages are typical
for summer

Figure 16. Typical flow pattern of the Cuyahoga River with the dominant southwest, west, and northwest wind directions (after Havens and Emerson, 1968).

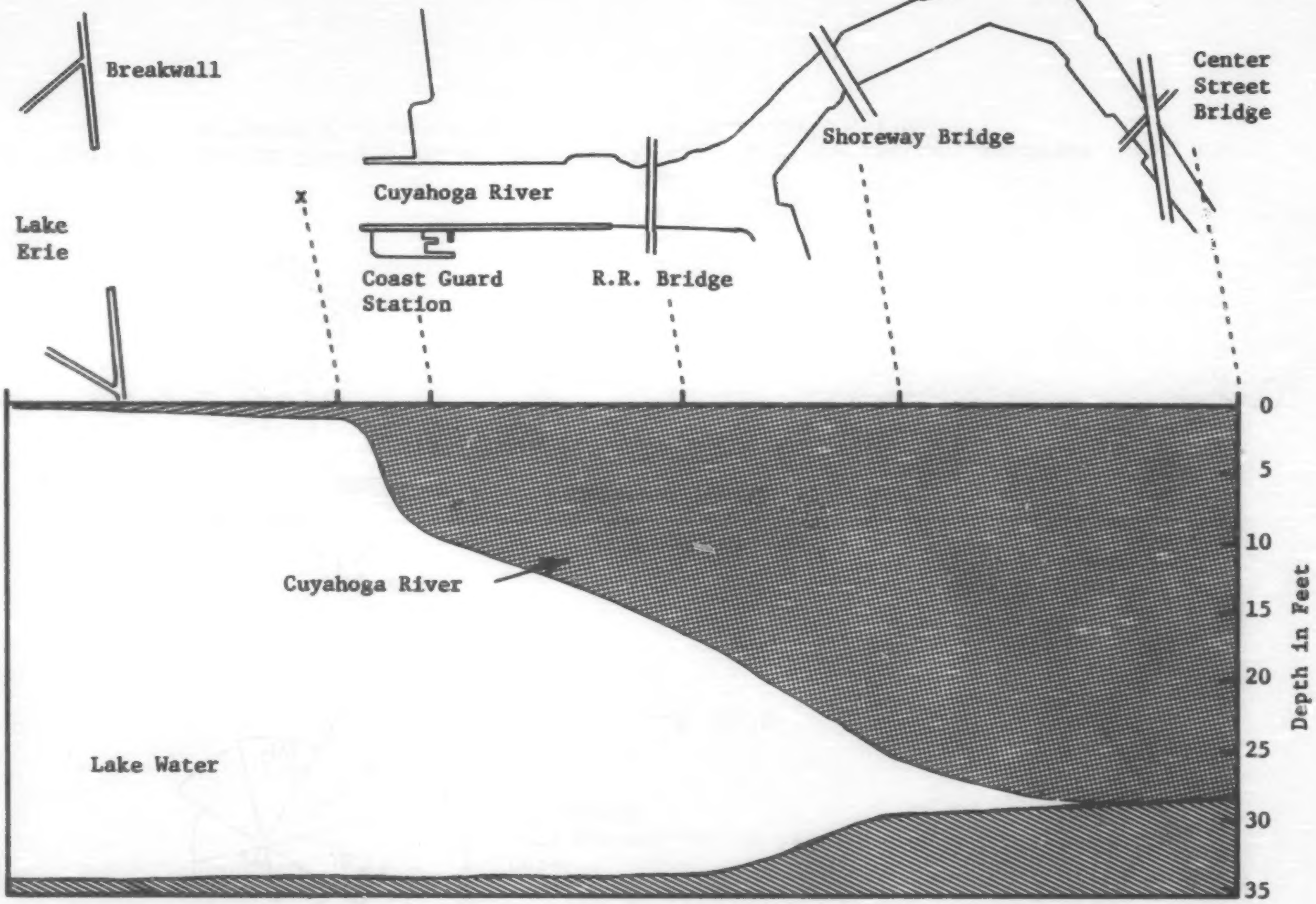

Breakwall
Lake
Erie
x
Cuyahoga River
Coast Guard
Station
R.R. Bridge
Shoreway Bridge
Center
Street
Bridge
Cuyahoga River
Lake Water
0
5
10
15
20
25
30
35
Depth in Feet

Figure 17. Cross section of lake water intrusion into Cuyahoga River from conductivity and dissolved oxygen measurements.

Chemical Investigations

There were three chemical investigations undertaken in this project. One examined the composition of bottom sediments in the near shore areas of the lake. Another analyzed the water chemistry in the same area. The third investigation dealt with examining possible buffering reactions of suspended sediments on four common cation in about fourteen miles of the downstream portion of the Cuyahoga River.

The benthic sediment investigation was performed by Dr. P. Olynyk of Cleveland State University concurrent with the biological studies of the zooplankton and benthos. This study of the composition of sediments in the near shore waters of Cleveland, shows little difference between present volatile solids (loss on ignition) and 1967 Federal Water Pollution Control Administration data. The Federal Water Pollution Control Administration (FWPCA) data for volatile solids averaged 21.40% for the central basin of Lake Erie and 6.30% for mid-lake central basin. The values reported in this study average 6.72% volatile solids, in close agreement with the mid-lake central basin.

In general, the organic content of the near shore sediments begins to increase in May until about October or November. This undoubtedly reflects the greater productivity during the late spring and summer. At four of the five sites for which data was obtained, there was a significant increase in organic content after July, possibly due to accumulation of algae after the fall overturn.

Total nitrogen shows 30 to 42% lower average values compared to 1967 data for central and western basin sediments respectively. The FWPCA (1968) values of .18% and .16% nitrogen for the central and mid-central basins compare with .11% found in this study.

In comparing sediment and supernatant nitrogen, a direct relationship can be observed, as shown in Figure 18. The parallelism between the curves indicates a direct relationship: as sediment total nitrogen (NT) increases, there is a corresponding increase in the supernatant NT. Organic matter is being added to the sediment faster than its nitrogen content can be solubilized by organisms.

Total phosphorus (PT) shows 67% and 28% higher average values compared to 1967 data for central and western basins respectively. This corresponds to values of .065% and .072% found by FWPCA in 1967, and a present value of .12%. These higher values may indicate a rapid accumulation of inorganic phosphates due to the fairly high iron content (30-142 mg/l). The comparison of monthly values indicates no trend, but high variation. It may be that the explanation is purely physical, resulting from shifting sediments due to weather, and from random sampling.

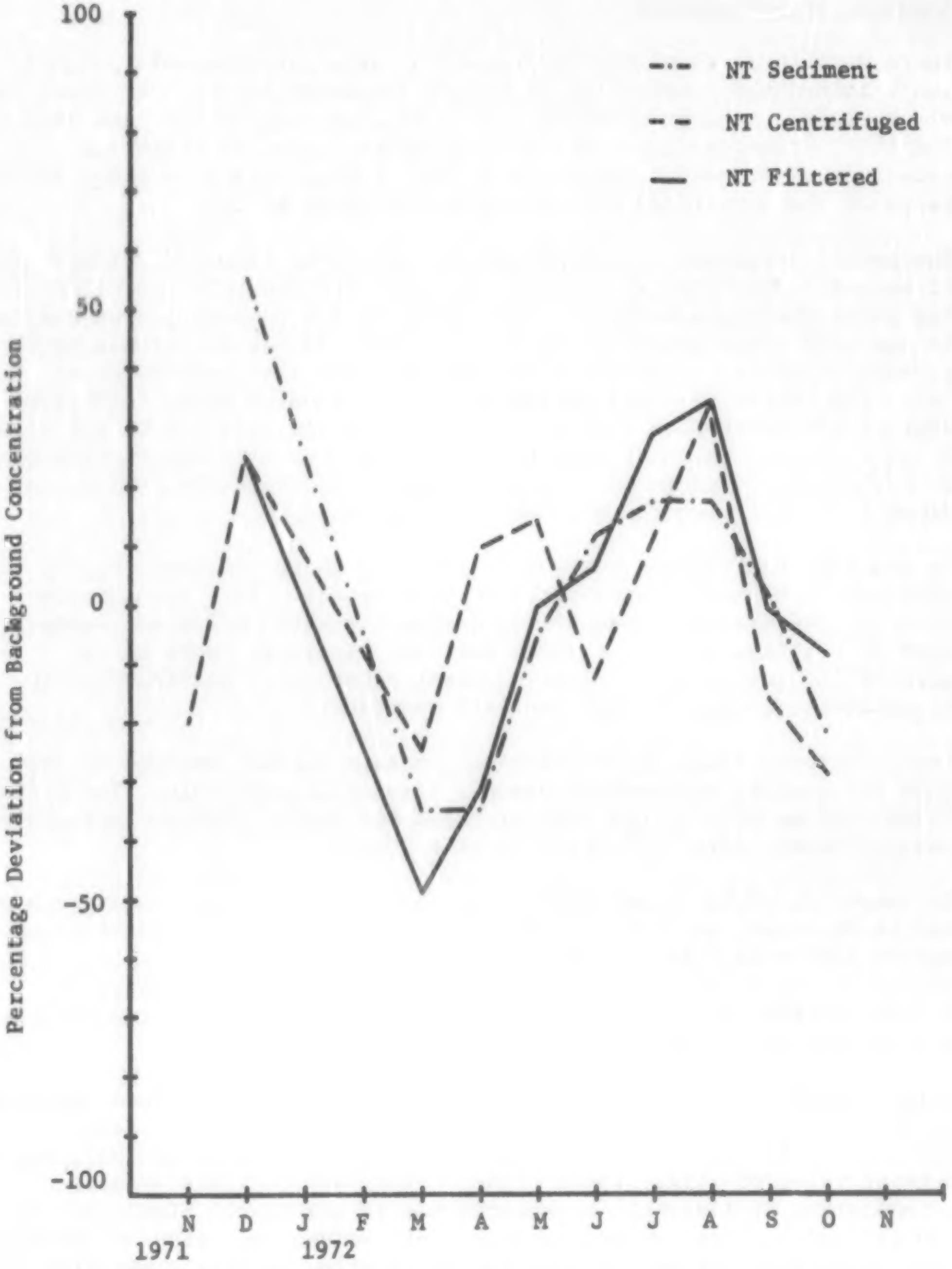


Figure 18. Comparison of Sediment and Supernatant Total N (Olynyk, 1973)

Examination of Figure 19 reveals a good inverse relationship between sediment PT and supernatant PT, especially if emphasis is placed upon total phsophorus centrifuged supernatant (PT-C) which will be done here. The inverse relationship is shown by increasing changes in total phosphorus in sediment (PT-Sed) and corresponding decreasing changes in PT-C. This correspondence appears each month except for May when severe storms occurred. The inverse relationship means that sedimentary PT goes into solution, especially during the summer months, at a greater rate than additions are made by living benthos, dead algae and other detritus. The sediment is serving as a phosphorus source.

Variations monthly in sediment data for phosphorus may indicate changes due to biological-chemical interactions when compared to nitrogen. Analysis of the NT and PT changes presented in Figure 20 leads to considerably more optimism in hypothesizing why the changes in composition occur. In November, 1971, both NT and PT are below the overall averages for the annual sampling period. In December, both parameters increased sharply, probably due to continued sedimentation of dead algae and inorganic phosphates after tha fall overturn. Samples could not be taken in January and February and during this approximately three month interval between samplings, the NT decreased sahrply while the PT increased. An acceptable explanation for this divergence is that biological and chemical actions have solubilized the organic nitrogen from the dead algae while continued sedimentation of inorganic phosphates has caused the PT to increase. From March to April the behavior of NT and PT again is opposite, NT increasing while PT decreased. This period indicates the vigorous new life of spring. Benthic productivity more than doubled from March to April, as shown by the benthos investigation. Benthic organisms, utilizing nutrients from the surrounding waters, increase the organic content of the sediment. Hence an increase in PT would be expected whereas a sharp decrease has occurred. This decrease in PT would be ascribed to the liberation of soluble phosphates in the lower anaerobic portion of the sediment due to agitation by storms after the loss of ice cover. From April to May there was a slight increase in both NT and PT probably due to benthic organism growth.

From May to June the PT increased sharply, while the NT decreased even more sharply. The drop in NT is readily explained by the drop in benthic productivity which occurred in this time span (R.G. Rolan), however the PT increase is anomalous since the PT contribution of the benthos has been lost and it would be expected that some PT loss should occur at this time due to the onset of summer anerobic conditions in the sediment. A possible explanation could be that storms in May swept inorganic phosphate rich sediment into the near shore area under study. Such sediment would also contribute to the observed reduced NT.

From June to July the situation became reversed: PT decreased while NT increased, even though benthic productivity remained essentially unchanged. Perhaps dead algae were beginning to accumulate on the sediment causing the NT to increase and produce the anerobic condition in

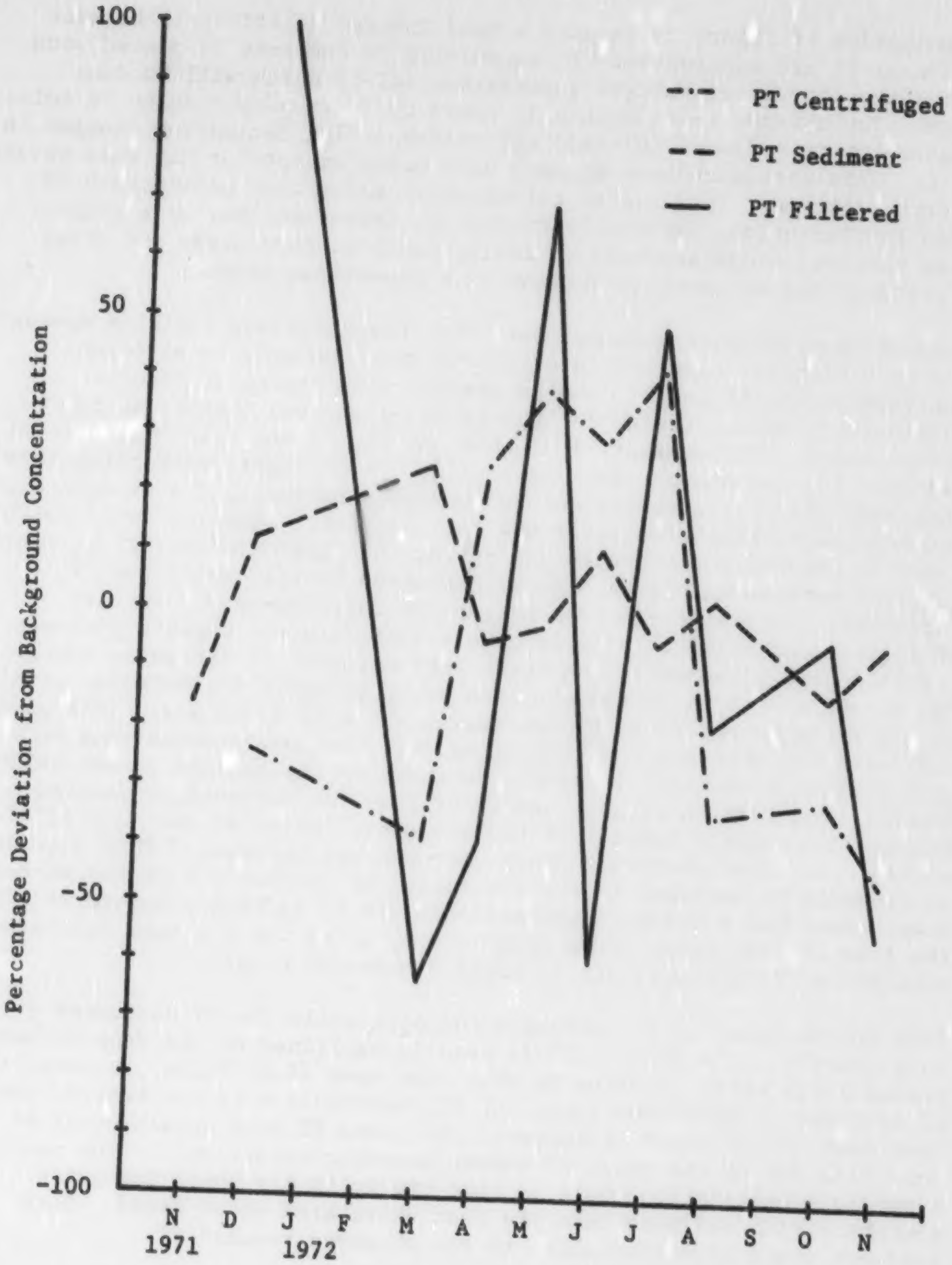


Figure 19. Comparison of Sediment and Supernatant Total P (Olynyk, 1973)

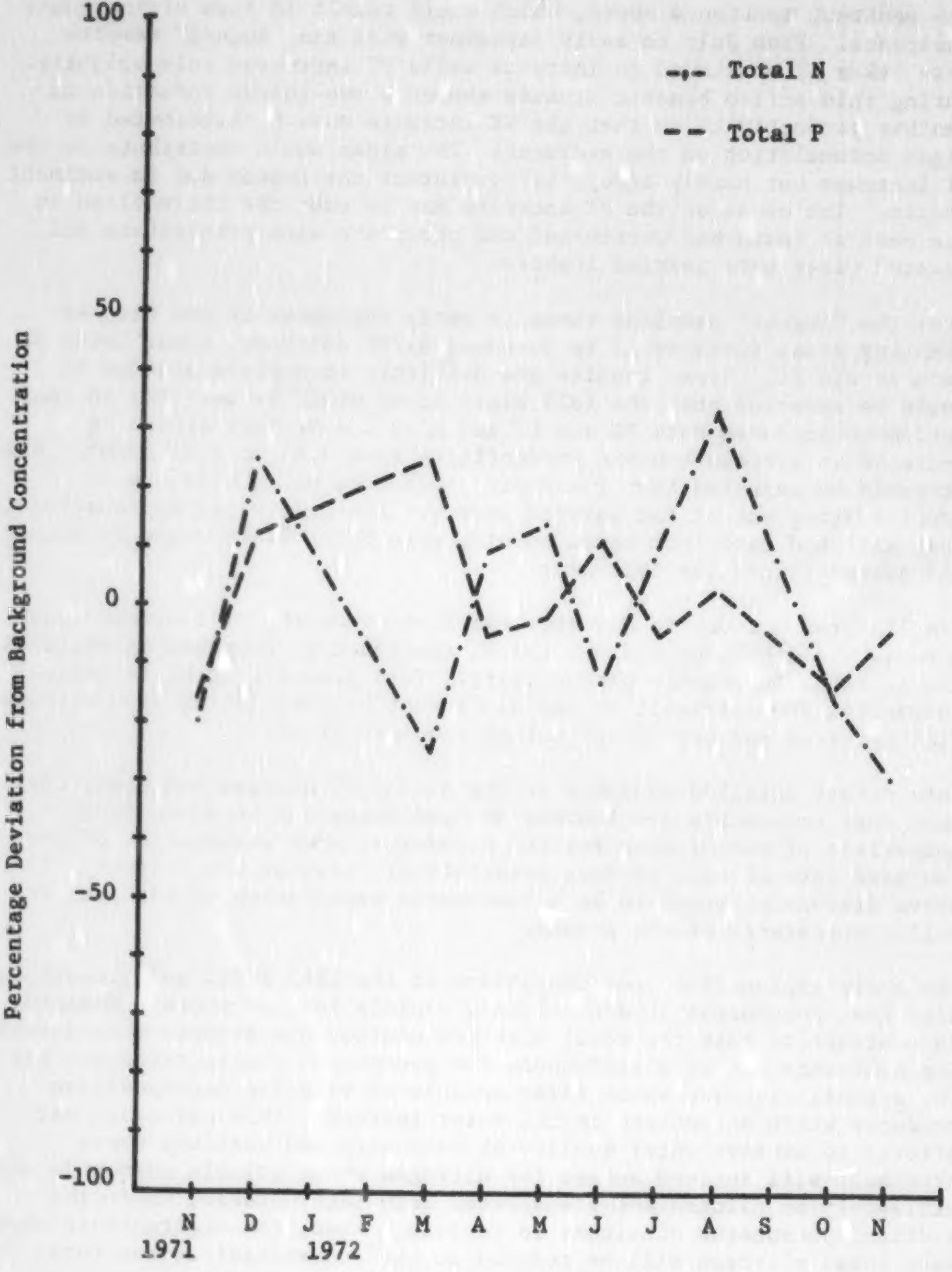


Figure 20. Sediment Composition Variation
(Olynyk, 1973)

the sediment mentioned above, which would result in loss of inorganic phosphate. From July to early September when the "August" samples were taken NT continued to increase while PT increased only slightly. During this period benthic studies showed a two-thirds reduction in benthic productivity so that the NT increase must be attributed to algae accumulation on the sediment. The algae would contribute to the PT increase but hardly enough to counteract the losses due to sediment anoxia. The cause of the PT increase may be that the thermocline in the central basin had overturned and phosphate rich precipitate and aerated water were carried inshore.

From the "August" sampling times in early September to the October sampling times (October 13 to November 3) NT decreased about twice as much as did PT. These results are difficult to explain because it would be expected that the fall algae bloom would be settling to the bottom to increase both NT and PT and also the benthos showed an increase in average benthic productivity from 0.84 to 1.81 gm/m^2. Also it would be expected that inorganic phosphates would still be precipitating out of the aerated waters. The only valid explanation is that silt and sand from shore erosion were being transported by storms and currents into the test area.

Finally from October to November sampling times the PT increased once more as would be expected but the NT continued to decrease in spite of the increase in benthic productivity. This behavior of NT is quite unexpected and difficult to explain except by postulating that nitrogen rich detritus had been swept out of the test areas.

This rather detailed analysis of the NT and PT changes has been done to show that reasonable conclusions or hypotheses can be drawn from comparison of two or more related parameters when examination of the isolated sets of data produce frustratingly tenuous conclusions. The above discussion seems to be a reasonable explanation of the peak and valley appearance of the graphs.

The above explanation, and comparison of the 1967 FWPCA and present data hint that phsophorus is accumulating rapidly in near shore sediments. In contrast to this the total nitrogen content has dropped considerably. The sediments act as a storehouse for phosphorus precipitates but not for organic nitrogen which forms soluble or volatile decomposition products which accumulate in the water instead. This may mean that efforts to improve water quality by secondary and tertiary waste treatment will succeed sooner for nitrogen whose soluble compounds will ultimately be diluted and transported into Lake Ontario, while the sediment phosphorus continues to recycle. Also, the supernatants show that total nitrogen will be reduced in the supernatant as the total nitrogen in the sediment decreases.

The supernatant studies show large increases in nitrate, ammonia, total nitrogen and alkalinity (inorganic carbon) compared to 1967 data.

Phosphorus, strangely, is of the same order as 1967 values while organic carbon has dropped by approximately 20%. Apparently soluble nitrogen species are accumulating in the water while total nitrogen is decreasing in the sediments. The reverse is the case with phosphorus. On this evidence it is impossible to conclude that Lake Erie water quality is improving at present.

On the basis of limited graphical comparisons some encouraging correlations between changes in sediment and supernatant parameters have been observed but it will be necessary to extend the value of the correlations by applying computerized programs to existing data.

The highest zone of pollution is found in the Cleveland Harbor. The eutrophic conditions are reflected by the sediment analysis. Site four had the highest values of LOI, organic carbon, total nitrogen, total phosphorus and grease. A comparison of site four to the average values is given in Table 13. In addition the supernatant analyses showed that the harbor had the highest total nitrogen, highest conductivity, highest inorganic carbon, among the highest total phosphorus, but it also had the lowest pH, nitrate, nitrite and organic carbon values. The results are tabulated in Table 14.

These data show that the harbor area is highly enriched. This is because the majority of flow of the Cuyahoga River passes through the harbor during north and northwesterly winds, which predominate in the Cleveland area. The harbor acts as a buffer zone between the Cuyahoga River and Lake Erie, reducing the impact of the river pollution on the lake by removing suspended solids, reducing oxygen demand and diluting dissolved solids. Thus the harbor is in very poor condition and warrants immediate restoration.

The examination of eleven metals showed some very interesting results. Mercury levels at times exceeded the levels in Minimata Bay, Japan. Mercury increases dramatically in April and May then falls off nearly as fast in June and July. The striking surge of mercury is undoubtedly due to spring run off carrying fallout from power plants, incinerators and metallurgical plants. Important questions to be answered are: why does the mercury decrease so rapidly? and where does it go?

One possible explanation is that, due to the high specific gravity of mercury, it sifts through the loose sediments until it meets a more compact interface. Thus, it would be decreased in the upper layers of sediment during the calm weather of the summer months and increased in the spring due to storms and high run off. Analysis of core samples could verify this.

Iron levels are greatly (50% to 75%) elevated over 1967 values for the central and western basins. Dumping of the Cuyahoga River and Cleveland Harbor dredgings by the U. S. Army Corps of Engineers is responsible for the high near shore iron levels. How much this affects phosphorus mobilization or stabilization has not been determined.

Table 13. COMPARISON OF HARBOR TO AVERAGE NEAR SHORE SEDIMENTS (mg/1)

Site	LOI	Organic carbon	NT	PT	Grease
Harbor #4	95	86.9	2.08	2.5	6.2
Average	69	55	1.1	1.2	1.7

Table 14. COMPARISON OF HARBOR (FILTERED) TO AVERAGE SUPERNATANT

Site	pH	Conductivity (umhos/cm)	NO_3^- (ppm)	NO_2^- (ppm)	NH_3 (ppm)	NT (ppm)	PT (ppm)	OC (ppm)
Harbor #4	7.5	308	.13	.027	10.3	13.3	.09	1.6
Average	7.8	270	.49	.054	3.3	4.2	.07	2.6

(Olynyk, 1973)

In general, the metals content decreased from early spring to late summer, then increased rapidly in the fall. This could be due to bottom turbulence during times of high winds in the spring and fall. The wave action would tend to wash the finer metallic silt into shore where it covers the coarser, more stable sand. During calm summer months, the silty material, rich in metals, would work its way into deeper waters. A determination of silicon dioxide content in the samples could have verified this, but no silicon dioxide analysis was made. Cadmium and cobalt showed the only continued decreases from October and November. This behavior has not been explained in light of such increase in the concentration of calcium, chromium, copper, iron, lead manganese, nickel and zinc. Other data for metals in Lake Erie sediments have not been located so that no conclusion can be made concerning whether metals are accumulating in the sediments.

The water chemistry investigation was conducted by the Water Quality Program. A major portion of the chemical data on the Cuyahoga River and Lake Erie was obtained in activities other than those connected specifically with this project. The Water Quality Program is an organizational unit of the City of Cleveland consisting of forty-seven scientists and technicians. The unit conducts ongoing programs in water quality research and monitoring, and implements water quality restoration projects. All the data gathered in those activities was made available for this project and will be placed in STORET.

To interpret the hundreds of analyses and parameters, the data was plotted graphically with a table top Hewlett-Packard computer.

In examining the water chemistry of the Cuyahoga River for 1972, a pronounced effect of the Cleveland area can be seen. Although the river is polluted by the time it passes the Southerly Waste Treatment Plant, the effect of the plant effluent can be noticed (Table 15). Maximum averages of major constituents are affected as follows: chlorides are increased by 15 mg/l, phosphorus by 1 mg/l, total dissolved solids by 125 mg/l, BOD by 3 mg/l, COD by 60 mg/l, and ammonia nitrogen by 3 mg/l. It appears that for the most part the plant's effluent does not contain great amounts of toxic metals (Table 16). On the average in 1972, the plant effluent increased the Cuyahoga River flow by about 105 mgd (Figure 21). The river flow upstream from the plant on monthly mean ranged from 250 mgd in August to about 2100 mgd in March during 1972.

The urban area and industrial discharges depress the water quality of the Cuyahoga River as it flows through Cleveland. Several relationships are evident. Although there are a number of relationships that affect dissolved oxygen in the river, the most obvious is an inverse relationship with temperature, with dissolved oxygen increasing with lower temperatures (Figure 22). The pronounced impact of chlorides from winter street salting and subsequent urban runoff is shown in Figure 23.

Suspended solids are greatly increased during storm flow. Examination of an isolated storm in June of 1972 shows that suspended solids suddenly

Table 15. CUYAHOGA RIVER WATER QUALITY IN 1972 (mg/1)

	Maximum and minimum mean concentrations							
	Above (Sta. 4) Southerly		Below (Sta. 5) Southerly		Lower (Sta. 6) Harvard		Center (Sta. 7) Street	
Substance	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
Dissolved oxygen	12.8	6.	12.8	6.	13.0	4.8	11.8	2.0
Temperature °C	22.	3.	22.	3.2	22.0	2.0	26.	6.2
Chloride	225.	60.	240.	60.	190.	60.0	290.	70.0
Total phosphorus	1.2	0.8	2.2	.8	1.4	0.6	0.8	0.2
Sulfate	110.	70.	115.	80.	125.0	90.0	150.	90.
Total dissolved solids	675.	350.	800.	400.	580.0	360.	900.	400.
Suspended solids	300.	100.	600.	100.	500.0	150.	100.	50.
BOD	15.	8.	18.	9.	15.	10.	15.	10.
COD	60.	40.	120.	60.	45.	15.	60.	15.
Total iron	5.5	1.8	8.	4.	--	--	--	--
Ammonia nitrogen	2.0	.8	5.0	1.0	5.0	1.0	6.5	2.0
Organic nitrogen	2.8	1.3	3.5	1.5	5.5	1.0	3.0	1.0
Alkalinity	140.	100.	150.	100.	150.	70.	140.	110.

Table 16. PERFORMANCE OF CLEVELAND WASTEWATER TREATMENT PLANTS IN MEETING DISCHARGE CRITERIA FOR HEAVY METALS DURING PERIOD FROM FEBRUARY 15, 1972 TO JULY 6, 1972

			Easterly			Southerly			Westerly	
Parameter	Criteria (mg/1)	Number Samples	Days Exceeding	Percent Exceeding	Number Samples	Days Exceeding	Percent Exceeding	Number Samples	Days Exceeding	Percent Exceeding
Mercury	0.005	48	0	0.0	47	0	0.0	47	0	0.0
Cadmium	0.01	77	6	7.9	61	6	9.8	77	28	36.4
Chromium (Total)	0.3	77	3	3.9	61	7	11.5	78	0	0.0
Copper	1.0	77	0	0.0	61	2	3.3	78	0	0.0
Iron (Total)	3.0	77	4	5.2	61	24	39.3	77	62	80.5
Nickel	1.0	75	0	0.0	61	0	0.0	76	0	0.0
Zinc	1.0	77	1	1.3	61	17	27.9	77	67	87.0

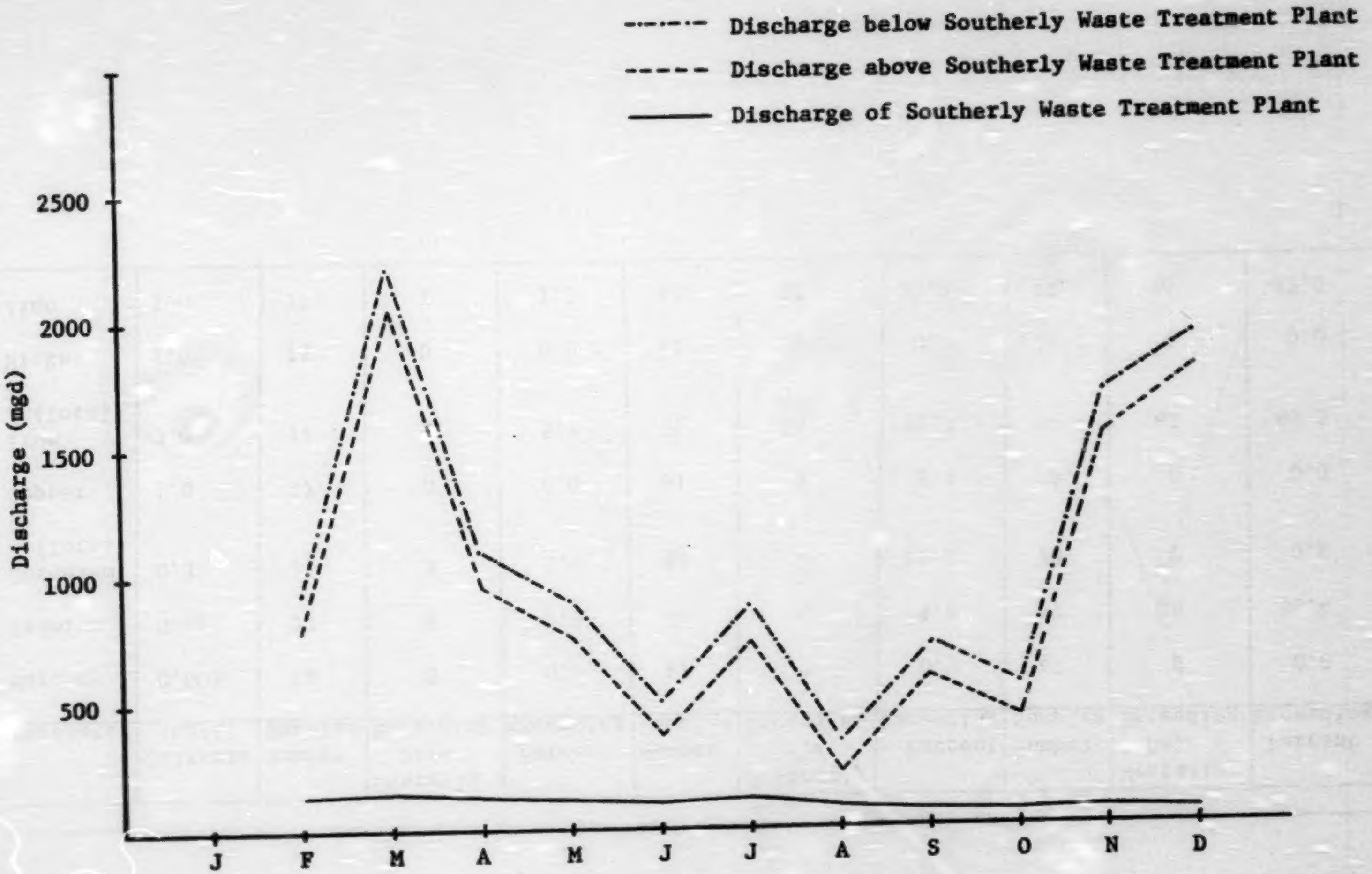


Figure 21. Cuyahoga River (mgd) discharge above and below Southerly Waste Treatment Plant in 1972

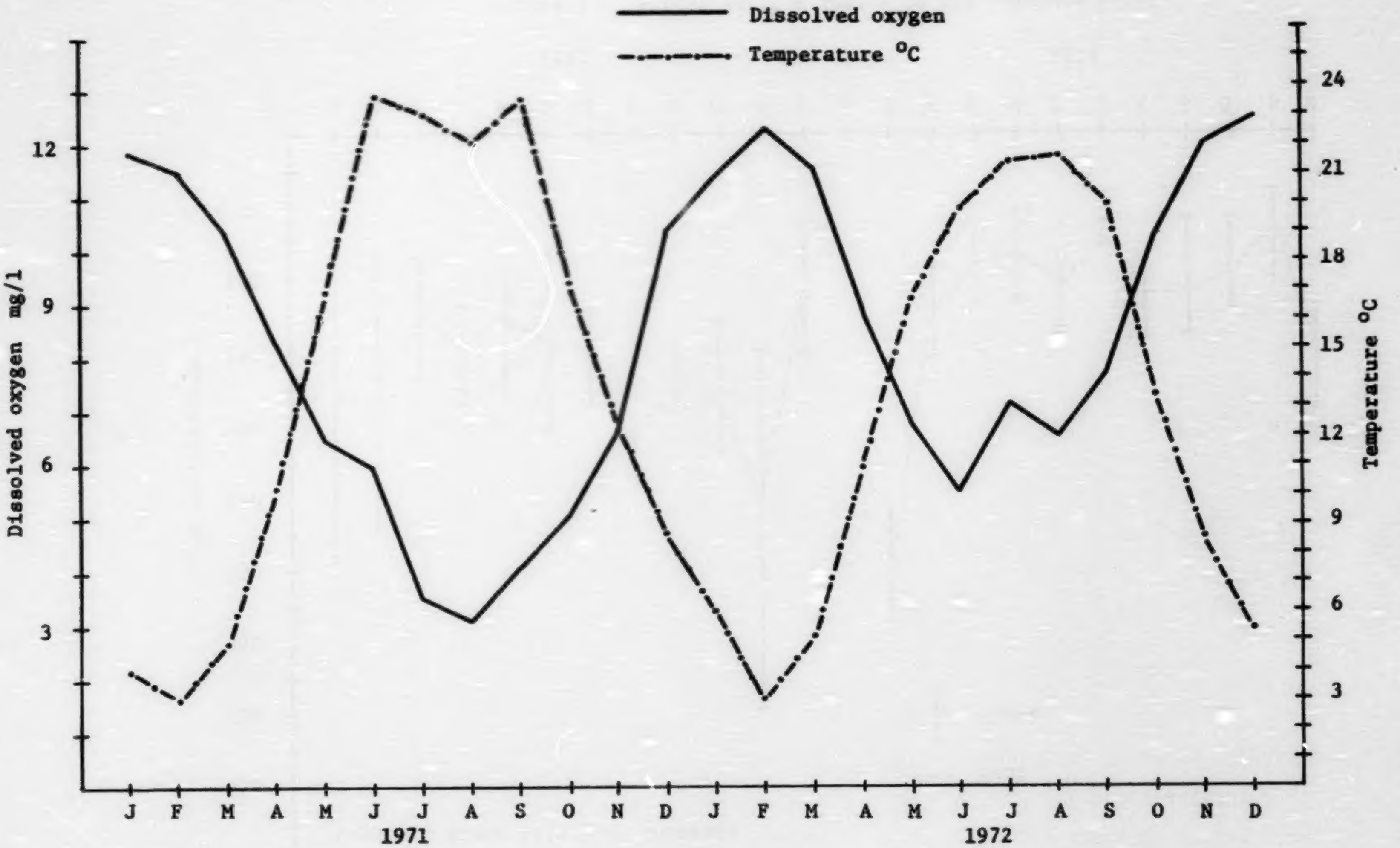


Figure 22. The inverse relationship between temperature and dissolved oxygen in the Cuyahoga River (Station 5)

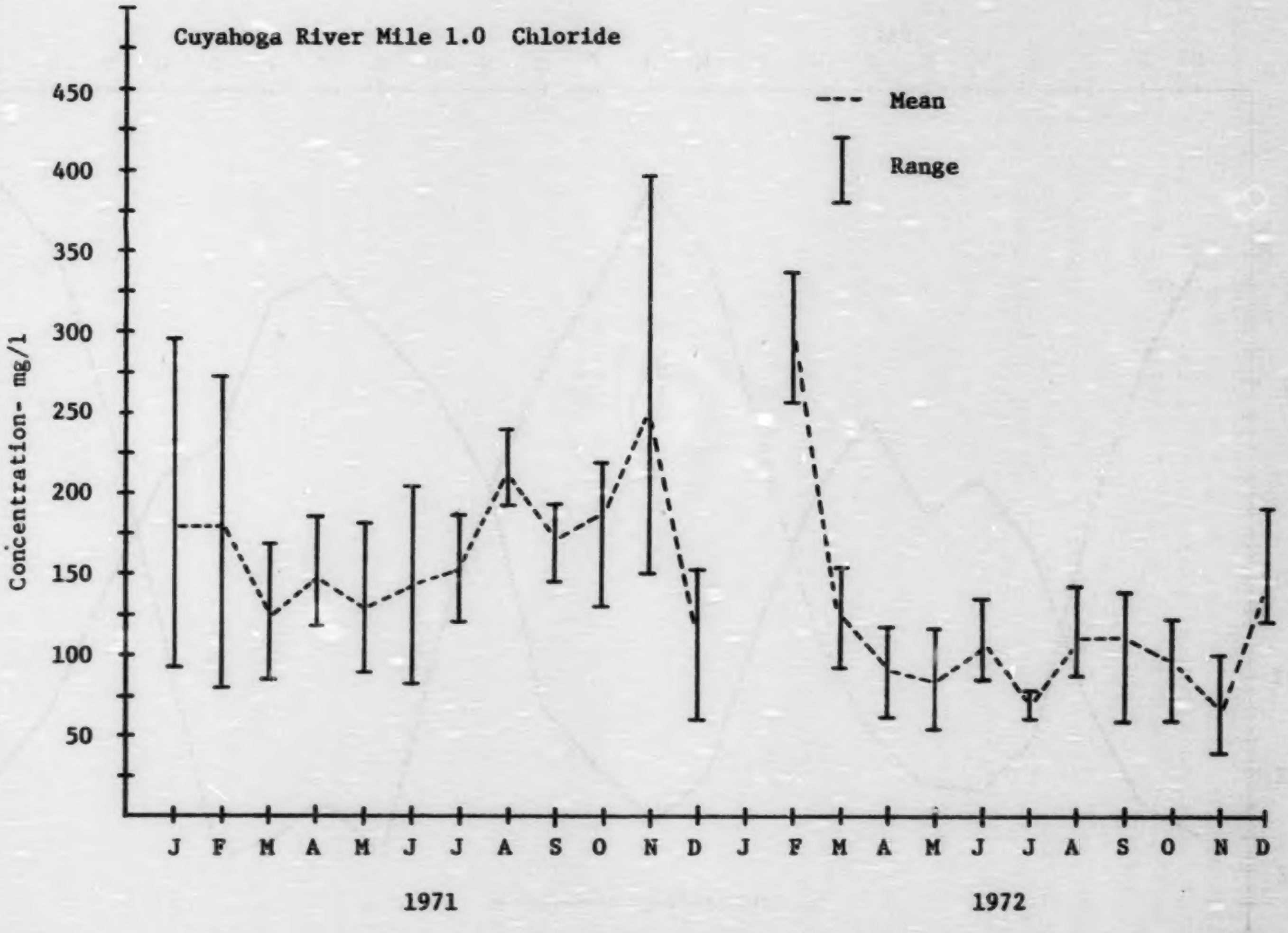


Figure 23. Street salting impact on the Cuyahoga River.

increase from 400 mg/l to over 4000 mg/l. The increase is related directly to the intensity and duration of the rainfall. The suspended solids concentration decreases rapidly as the flow enters the navigation channel, where suspended particles settle out and accumulate as sediments. The suspended matter is about ninety percent clay and soil particles.

The dilution effect of Lake Erie is evident in the navigation channel. At the mouth, the river behaves like an estuary. The lake levels influence the river reversing its flow and diluting the contaminants. The velocity of the river flow into the lake is greatly reduced by the harbor enclosure which deflects part of the flow east into the harbor behind the breakwall.

Another relationship that is evident in the Cuyahoga River and applies to other bodies of water is the relationship between concentration, pollution loadings, and flow (Figure 24). This relationship shows that concentrations of pollutants may decrease even though the loadings may increase. The concentrations are greatly dependent on the quantity of the flow. This factor is significant in assessing the effectiveness of pollution abatement, illustrating the importance of hydrologic measurements. In rapidly decreasing flow situations, the reverse may be true -- the concentrations may increase, although pollution loadings are decreased.

The overall lake chemistry in the study area showed localized zones of water quality depression in the near shore waters. The pollutant concentration zones are directly correlated with point source emissions.

The streams, especially, the Cuyahoga River, and the two wastewater treatment plants on the Lake (The Easterly and The Westerly) act as point sources of pollution as shown in Figure 12. The wastewater treatment plant effluent loading in 1972 for total phosphorus, suspended solids, and biochemical oxygen demand are shown in Table 17A. The values are based on average flow and average effluent concentrations and do not take into consideration bypass and storm flow loadings.

Analysis of 1972 pollutant concentrations by the wastewater treatment plants and mouths of urban creeks showed higher values than those found in the open Lake. Total dissolved solids ranged from about 400 to 1200 mg/l in the near shore areas to about 200 mg/l in the open Lake waters about 3 kilometers from the shore. The BOD values in the creeks ranged from 10 - 50 mg/l with average values of 10 mg/l observed throughout most of the period. Open Lake waters had about 1.5 mg/l BOD approximately 3 kilometers from the shore. Total phosphorus values ranged from about 2 to 5 mg/l to about 0.1 to 0.2 mg/l in the open Lake waters about 3 kilometers from the shore.

Other pollutant concentrations exhibited similar gradation from the near shore to open Lake. For example the average monthly values of

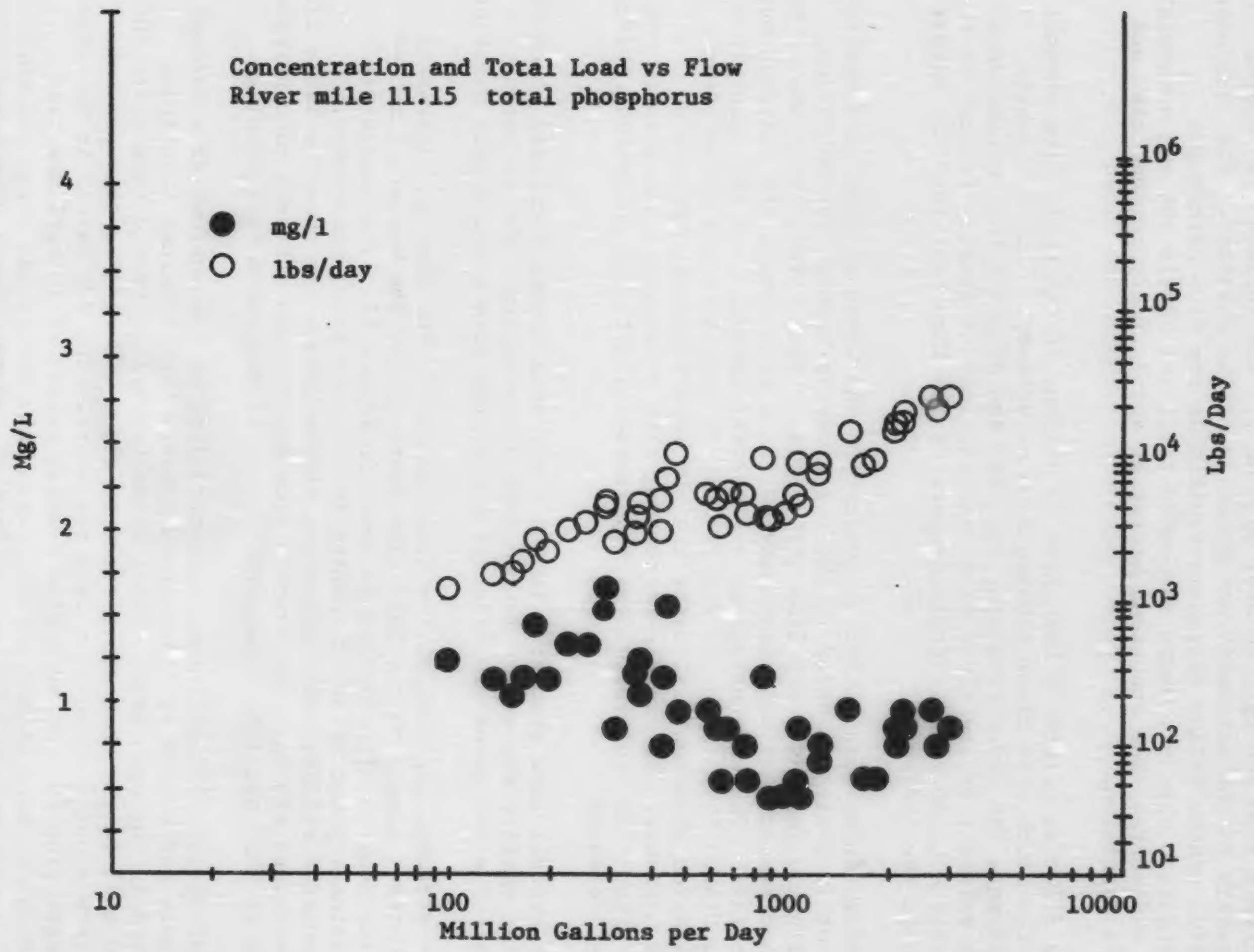


Figure 24. Concentration and total phosphorus load vs flow in the Cuyahoga River at 11.15 miles upstream from the mouth of the River.

Table 17A. CLEVELAND WASTEWATER TREATMENT PLANT POLLUTION LOADINGS IN THE EFFLUENT FOR 1972

Parameter	Easterly	Westerly	Southerly
Biochemical Oxygen Demand			
Concentration (mg/l)			
Raw	132	216	196
Effluent	25	147	25
Loading (tons/yr)	4,734,797	8,514,101	24,125,940
Suspended Solids			
Concentration (mg/l)			
Raw	157	198	294
Effluent	38	116	40
Loading (tons/yr)	7,168,749	6,740,571	38,426,397
Total Phosphorus			
Concentration (mg/l)			
Raw	4.6	5.7	7.4
Effluent	3.0	4.5	2.3
Loading (tons/yr)	589,472	261,972	2,237,486

sulfate in the near shore ranged from about 90 mg/l to about 220 mg/l. In the open Lake about 3 kilometers out, the sulfate values ranged from about 14 mg/l to about 40 mg/l. The chloride values for monthly means ranged in the near shore from about 60 mg/l to about 210 mg/l. In the open Lake the chloride mean monthly values ranged from about 20 mg/l to about 40 mg/l. Chloride concentrations were much higher in the winter months in the near shore as well as the open Lake.

The concentrations of these pollutants and their dispersion is greatly affected by Lake currents and wind patterns. Vertical as well as horizontal distribution of the pollutants is highly variable in the open Lake and near shore waters. This effect is most noticeable by dissolved oxygen concentrations which range from about 6 mg/l to about 14 mg/l with no remarkably great variance from open near shore waters to open Lake waters. The most pronounced difference from this condition is observed in the area behind the breakwall of the Cleveland Harbor where lower average values of dissolved oxygen are measured throughout the year. The Harbor area has two basic factors operating that depress the dissolved oxygen in the area. One factor is the oxygen demanding wastes from the Cuyahoga River, the other is the confining effect of the breakwall which prevents open Lake circulation. Average monthly values of dissolved oxygen range from about 2 mg/l to 13 mg/l. All these values, however, deal primarily with the top 20 feet of the water.

One of the most pronounced effects on the near shore water quality was observed from bacterial contamination. Table 18 shows the percentage of non-chlorination of the wastewater treatment plant discharges. Figure 25 shows the fecal coliforms discharged in the plant effluent. The water quality standard for the two plants discharging to Lake Erie is stated in the regulations of the former Water Pollution Control Board of the Ohio Department of Health:

> The fecal coliform content (either MPN or MF count) not to exceed 200 per 100 ml as a monthly geometric mean based on not less than five samples per month; nor exceed 400 per 100 ml in more than ten percent of all samples taken during the month.

The Easterly Wastewater Treatment Plant met this standard only four months in 1972, and the Westerly plant met the standard in only three months. Inasmuch that both of these plants discharge their effluent by two of the largest public beaches in the City, the recreational impact was severe, with the beaches being closed to bathers. Most of the bacterial contamination was confined in the near shore areas. Open Lake water (3 kilometers and out) showed very little impact. The coliform count in the near shore ranged from 10^3 to 10^6/100 ml whereas, in the open Lake the mean value fell below 400/100 ml. Occasional values in excess of 50,000/100 ml have been observed indicating that sewage discharge effect is observable even in the open Lake near the intakes of water filtration plants.

Table 18. NUMBER OF SAMPLE DAYS OF CHLORINATION OR NON CHLORINATION FOR 1971 AND 1972

Plant	Number of Days When Effluent was Chlorinated 1971	1972	Number of Days When Effluent was Non Chlorinated 1971	1972	Percentage of Days Chlorinated 1971	1972
Southerly	0	143	60	51	0	70.5
Easterly	18	189	47	17	28	92
Westerly	0	126	23	72	0	64

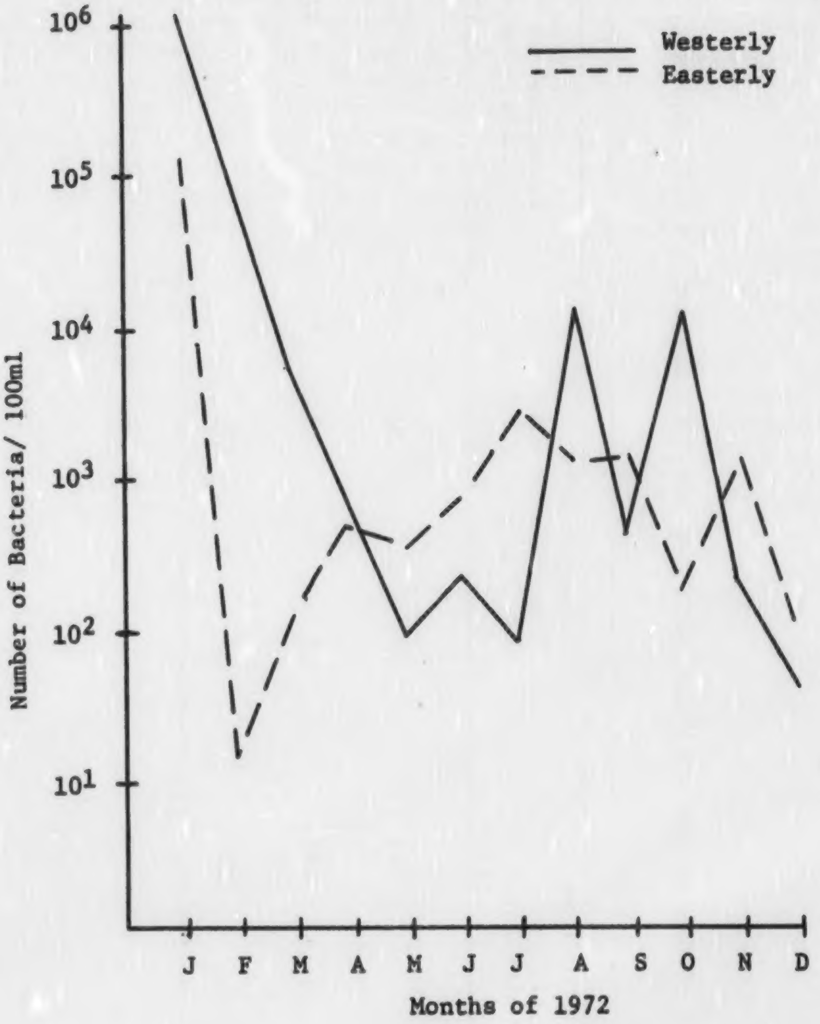


Figure 25. Fecal coliforms vs. geometric means monthly average in the effluent of the two wastewater treatment plants on Lake Erie.

The cation exchange reaction study was designed and conducted by Dr. J. Hower of Case Western Reserve. The purpose of the project was to determine the buffering effects of suspended sediments on potassium, sodium, calcium and magnesium in the Cuyahoga River. Cation exchange capacities and selectivity numbers were determined to prove or disprove the existence of such buffering action. The basic principles of this study were that the clay minerals composing some of the suspended sediment in rivers have an active negative surface which is neutralized by adsorbed cations. This ion-exchange characteristic of sediment is a controlling factor on the concentrations of dissolved ions. In establishing such a buffering action in the Cuyahoga River, it was hoped that this data would establish a chemical baseline to monitor chemical changes in the river.

The study did demonstrate such a buffering action, but it showed a pronounced possibility that bottom sediments exert a strong influence. This study, also, showed indirectly that variables such as flow and industrial discharges distort the results. Much additional work must be done, especially on bottom sediments and other elements, to establish the usefulness and viability of such reactions in relation to water quality monitoring.

In evaluating this study in conjunction with the benthic and water chemistry investigations a number of areas of necessary research became apparent. The author gratefully acknowledges the help of Dr. R. W. Manus of Kent State University who developed a framework for future studies.

Future work should center on determining the sources and dynamics of phosphorus and of toxic materials that are present or being contributed to the lower twelve miles of the Cuyahoga River and the Cleveland Harbor area. This work should include water chemistry and suspended sediments, and with emphasis on the nature and chemistry of bottom sediments and interstitial waters. To accomplish a thorough evaluation, the preservation of in situ conditions should be assured through proper methods of coring and glove box procedures. The work should cover the basic aspects as outlined:

1. Delineation of nature of input sources of both phosphorus and deleterious metals (eg. chromium, cadmium, copper, lead, mercury, zinc):

    A. In solution
    B. Adsorbed on suspended sediment
    C. Relationship to storm runoff suspended load (clays)
    D. Consideration of river bottom sediment as a sink and source (exchange and buffering mechanism)
    E. Temporal variations in input to river and to lake (relate to measured parameters, eg. dissolved oxygen)
    F. Preventive mechanisms

2. Characterization of bottom sediment and interstitial water:

   A. Fe^{+2}/Fe^{+3}, alkalinity, phosphorus, dissolved oxygen, Eh, pH, calcium, etc.
   B. Role of clays as sinks for more exotic, potentially harmful metals (eg. chromium, cadmium, copper, lead, mercury, zinc)
   C. Buffering capacity of bottom sediments (including temporal variation, eg.). If phosphorus is removed from a river (by sewage diversion) will sediment act as a buffer and release phosphorus to lake input water?
   D. Identification of precipitated form of phosphorus presumably present under aerobic river and lake bottom conditions.
   E. Relationship of interstitial water chemistry to overlying water chemistry.
   F. Effect of Eh (or dissolved oxygen) on buffering capacity of clays. Aeration could lower exchange capacity of clays thus releasing adsorbed metals.
   G. Temporal variation of all parameters (eg. dissolved oxygen, interstitial phosphorus)
   H. Development of a chemical mass balance between sediment and interstitial water especially as it relates to aerobic versus anoxic conditions.
   I. Development of equilibrium models based on analytical data. These should lead to computed predictive models regarding release, uptake, or equilibrium conditions for phosphorus or the deleterious elements. It is anticipated that phosphorus release can be related to a critical dissolved oxygen level.

3. Determination of effect of river modification schemes and development of improved systems:

   A. Need for maintenance of critical dissolved oxygen level along course of river can probably be established. This will relate to need to maintain adequate flow in river and, possibly, need to aerate waste water effluents.
   B. Investigate conditions under which the precipitation or adsorption of phsophorus can be made to be irreversible under the chemical regime which presently (or will) exist, eg. utilization of aluminum complexes or aluminum rich clays.

As part of Phase II of the Program these proposed investigations would be geared to establish ameliorative measures as well as define additional baselines.

Biological System

The study examined basically five biological systems. These were accomplished through five separate investigations:

Cladophora
Phytoplankton
Zooplankton
Benthos
Fishes

The Cladophora study was conducted to assess the abundance and growth patterns, its response to nitrogen and phosphorus input in the water, and the feasibility of using this growth and response measurement as indicators of water quality in the study area. The investigation showed that Cladophora growth in the Cleveland area during the study period was nominal. The floating substrate method was found to be unsuitable for study of Cladophora growth in conditions having exposed areas or large bodies of water as in the study area. The investigation established that Cladophora growth can be measured with floating substrates, but in terms of flexibility, ease and economics it was found to be unsuitable. However, the observed differences in Cladophora growth are not necessarily related to differences in water quality.

The phytoplankton investigation was conducted to determine the various phytoplankton populations in growth patterns, abundance, and seasonal variation. The gross numbers of phytoplankton were converted to biomass. The highest average biomass occurred during September. The highest individual biomass occurred at station one, the western most station which is affected least by inputs along the Cleveland Harbor area. During the summer months the green algae accounted for the greatest proportion of biomass, with the single dinoflaggelate genera, Ceratium being second. At no time did the blue-green algae constitute a major portion of the biomass. The blue-greens were at the highest peak in September, but only constituted 10% of total biomass. During the winter months, the diatoms comprised the major portion of the biomass. In effect, this study showed that the experimental design employed will not describe the effects of point sources of pollution upon phytoplankton populations for two basic reasons; (1) insufficient data gathering missed short term fluctuations in phytoplankton population and density, and (2) insufficient knowledge of water flow patterns to predict which sources are affecting a particular area. Pertinent graphs of the phytoplankton study are given by Figures 26 through 28.

Zooplankton communities of Lake Erie in the Cleveland nearshore areas were investigated by Dr. R. G. Rolan of Cleveland State University, and his full study was published in the 1973 Proceedings of the International Association for Great Lakes Research. His study is summarized in the following paragraphs.

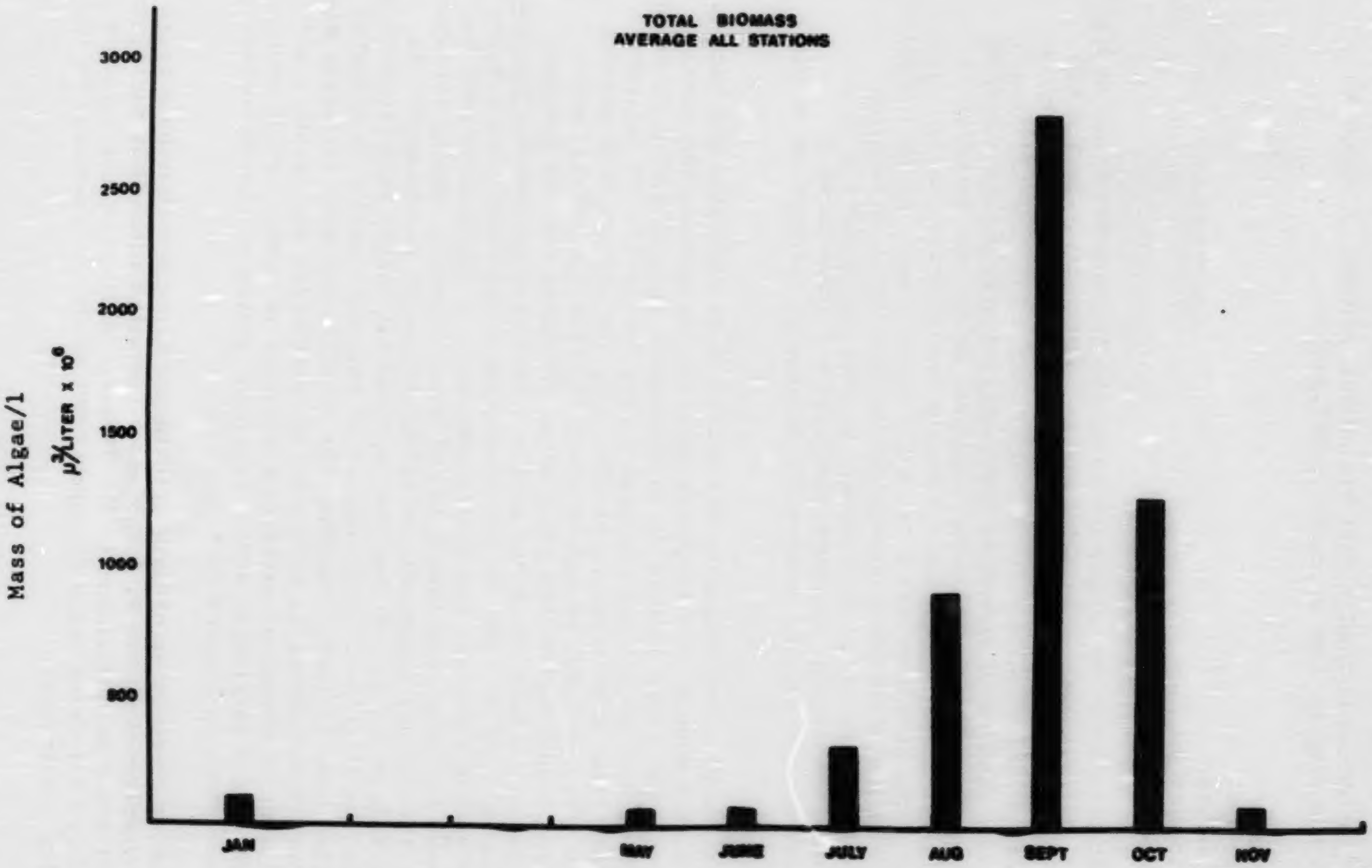


Figure 26. Total biomass of phytoplankton for each month of the study. These data are the mean total phytoplankton biomasses of the area calculated by combining all data from all stations for each month in 1972. (Alldridge, 1973)

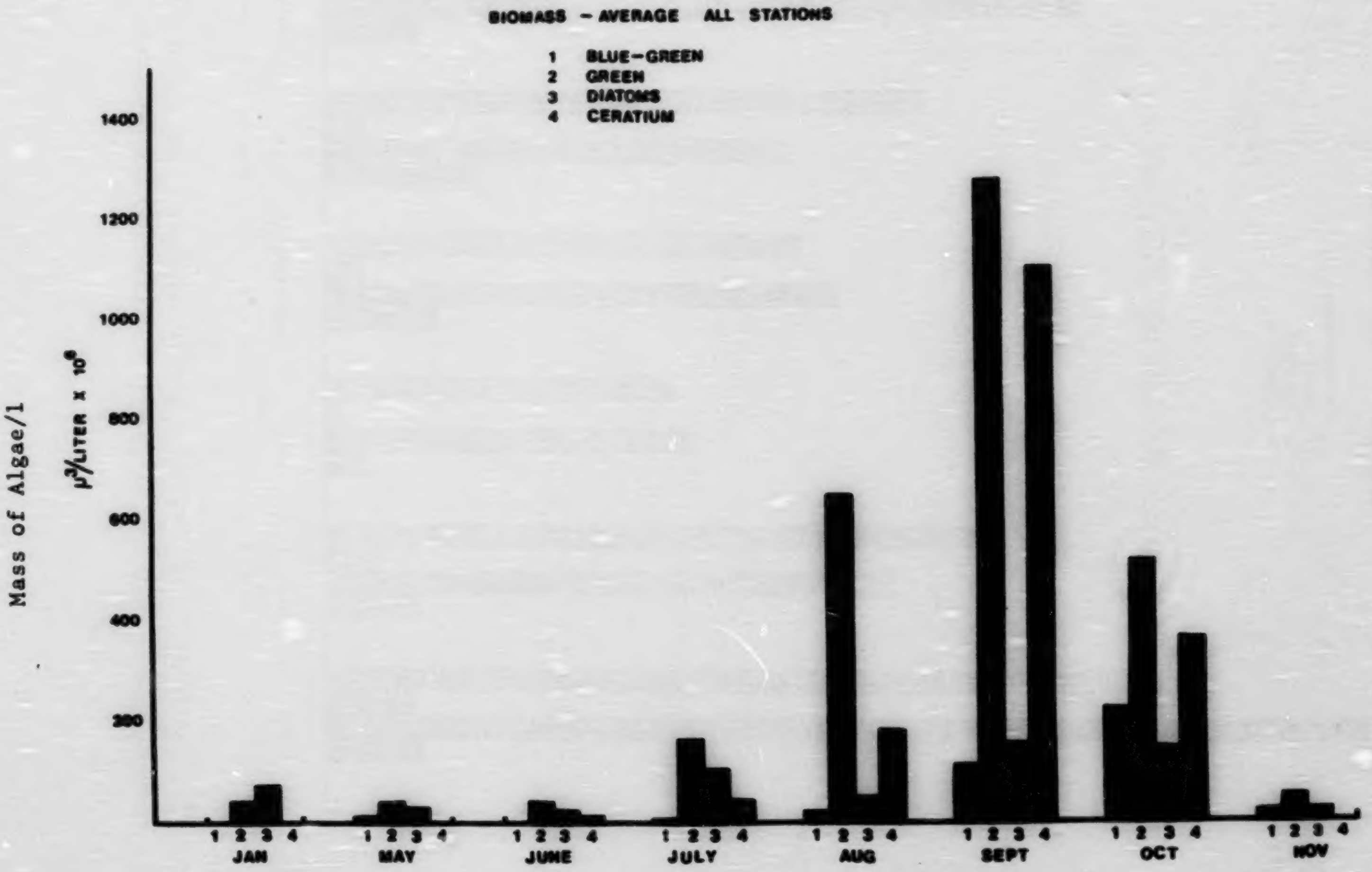


Figure 27. Mean total biomass of four different groups of algae for all stations for all months in 1972. (Alldridge, 1973)

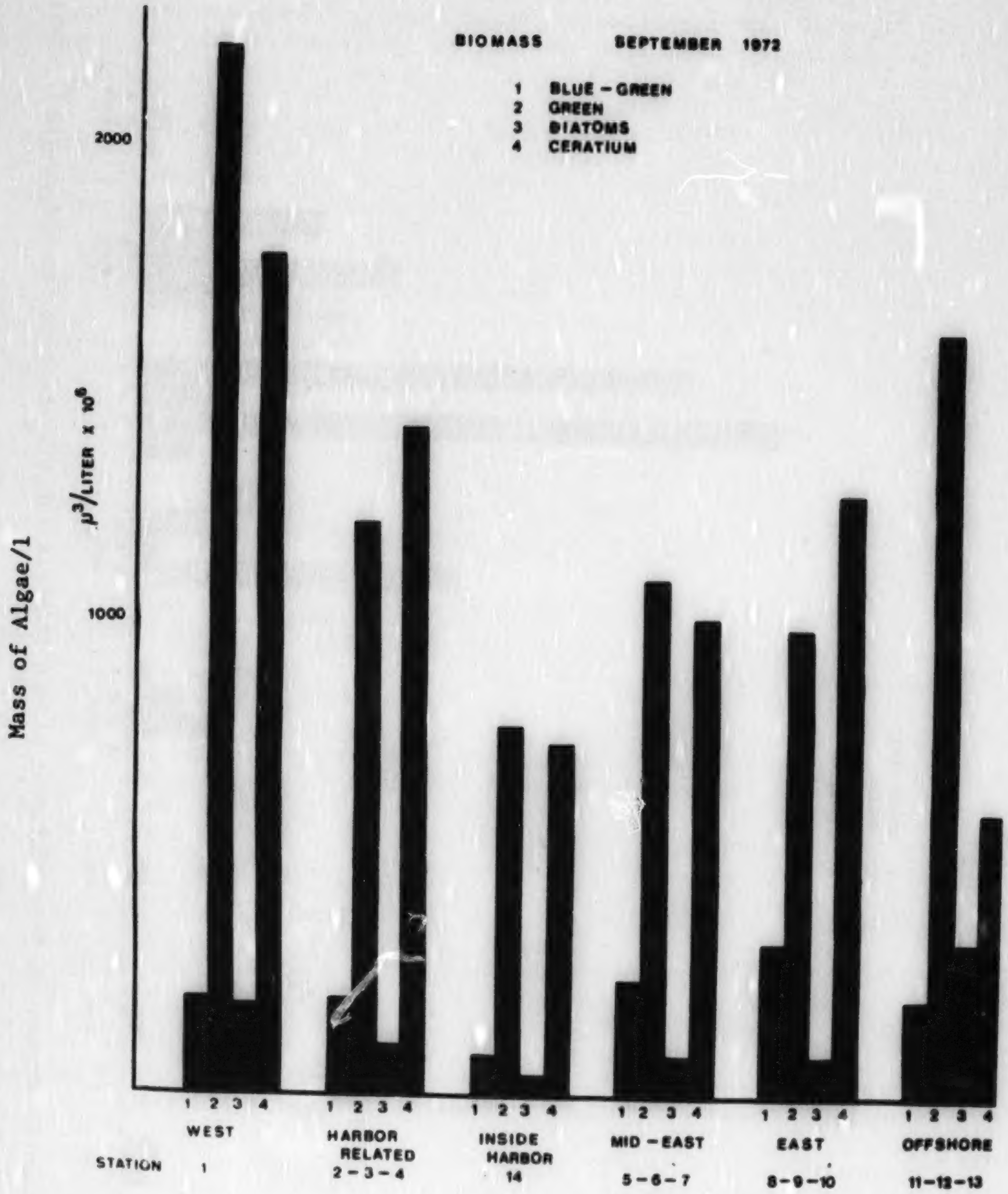


Figure 28. Distribution of the major groups of algae. Data from geographically related stations are grouped (Alldridge, 1973).

It is well known that changing water quality conditions are responsible for changes in the number, type and diversity of the biota present in an aquatic system.

Of the various groups of organisms, the zooplankton are often overlooked as indicators of changing chemical quality of the aquatic system. The zooplankton have several attributes which make them desirable as water quality indicators, particularly in the Cleveland near shore areas of Lake Erie. Such attributes include: 1) the zooplankton lend themselves reliably to fairly simple methods of quantitative sampling; 2) they are a major source of food for all types of fish; 3) being grazing animals, they are responsive to quality changes in the phytoplankton which in turn are responsive to quality changes in the water; 4) two previous quantitative studies of the zooplankton have been performed in the Cleveland near shore area within the past twenty-five years; 5) comparative studies of zooplankton in the western basin of Lake Erie have been made regularly for the past forty years; 6) although the extent is still uncertain for the entire group, a wealth of data exists for several members pertaining to their physiological requirements and tolerances to various levels of "pollution".

For this study, ten locations along a ten kilometer profile were sampled at approximate monthly intervals from September 1971 through January 1973. With the exception of June 1972, when samples were collected using water pumps, all samples were collected with plankton nets (333 u apurture) drawn vertically up from the bottom. The samples were field preserved in buffered formalin and returned to the laboratory for processing. Because of method of collection, only the adult cladocerans and capepods were collected quantitatively and thus are the only components of the zooplankton community considered in analysis and comparisons of changes in community structure with time.

Analysis of community structure was performed using the Shannon-Weaver index of diversity, the equitability component, theoretical maximum of species diversity and relative abundance of the two major groups were also computed. Data obtained from the two earlier zooplankton studies were also anlayzed.

Comparison of the results of the present study with those of previous studies in the Cleveland area and in the western basin shows: 1) greater fluctuations in maximum and minimum densities when compared to either the 1950-51 or 1956-57 study; 2) very close agreement in the circum-annual density patterns; 3) a slight decrease in mean density of both cladocerans and copepods in the 1971-72 study as compared to the 1956-57 study; 4) mean density increase of three to ten times for copepods and cladoceran respectively during the 1956-57 study as compared to the 1950-51 study; 5) although the copepod mean density has remained slightly greater than the cladoceran mean density, maximum abundance has shifted in favor of the cladocerans; 6) the shift in maximum abundance is very similar to the shift which occurred in the western basin during the middle 1950's; 7) Limnocalanus macrurus, an organism which resides in the hypolimnion, was not present in the 1956-57 or the 1971-72 studies, perhaps due to progressive decrease in oxygen in the hypolimnion; 8) significant numbers of both Diaptomus reighardi and Eurytemore affinis were found in the present study, and Diaptomus sciciloedis, a pond species, appears to be increasing in numbers.

The changes in total and relative abundances of the two groups indicates that eutrophication is in an advancing state, being roughly similar to that of the western basin, but ten to fifteen years later. This is supported by the shift of species from low temperature, high oxygen requiring species to those which can tolerate warmer temperature and greater nutrients. The greater fluctuations in density would seem to indicate a greater environmental stress being placed upon the organisms.

This study, although broad in scope, did not show how the effects of point sources of pollution affects the density of the zooplankton. In order to delineate such effects, a narrower area should be chosen and sampled more extensively in both time and space.

The benthos study was designed by Dr. R. G. Rolan to delineate the benthic macroinvertebrate communities of the Cleveland shore of Lake Erie. A delineation diagram is given by Figure 29.This study examined fourteen sampling locations from September 1971 to December 1972. The benthos abundance was estimated, and a preliminary water quality evaluation of this area was formed using the data. Benthic macroinvertebrates are valuable indicators of water quality because they are so easily sampled and are essentially permanent inhabitants of the bottom. Changes in the benthic invertebrate community occur in response to changes in temperature regimes, to variations in erosion and siltation patterns, and to changes in the concentration of organic or industrial wastes. Species composition and abundances of species change with environmental flux. The magnitude of this change depends primarily on the nature and severity of the environmental change.

Seventy-one benthic invertebrate species were found with the largest number of species belonging to aquatic Annilida, followed closely by Sphaerid clams. The most universal of these species were the tubified oligochaetes, the most common being Limnodrilus hoffmeisteri, L. cervix and Pelescolex multisetosus. Most of the clams were various species of Pisidium. Other invertebrates found: a) in at least fifty percent of the locations included leeches, pulmonate snails, and aquatic fly larvae; and b) in less than fifty percent of the locations included coelentrates, flatworms, nematocles, fresh-water polychaetes, gill-breathing snails, water fleas, scuds, aquatic sow bugs, mayflies, aquatic beetles, and water mites.

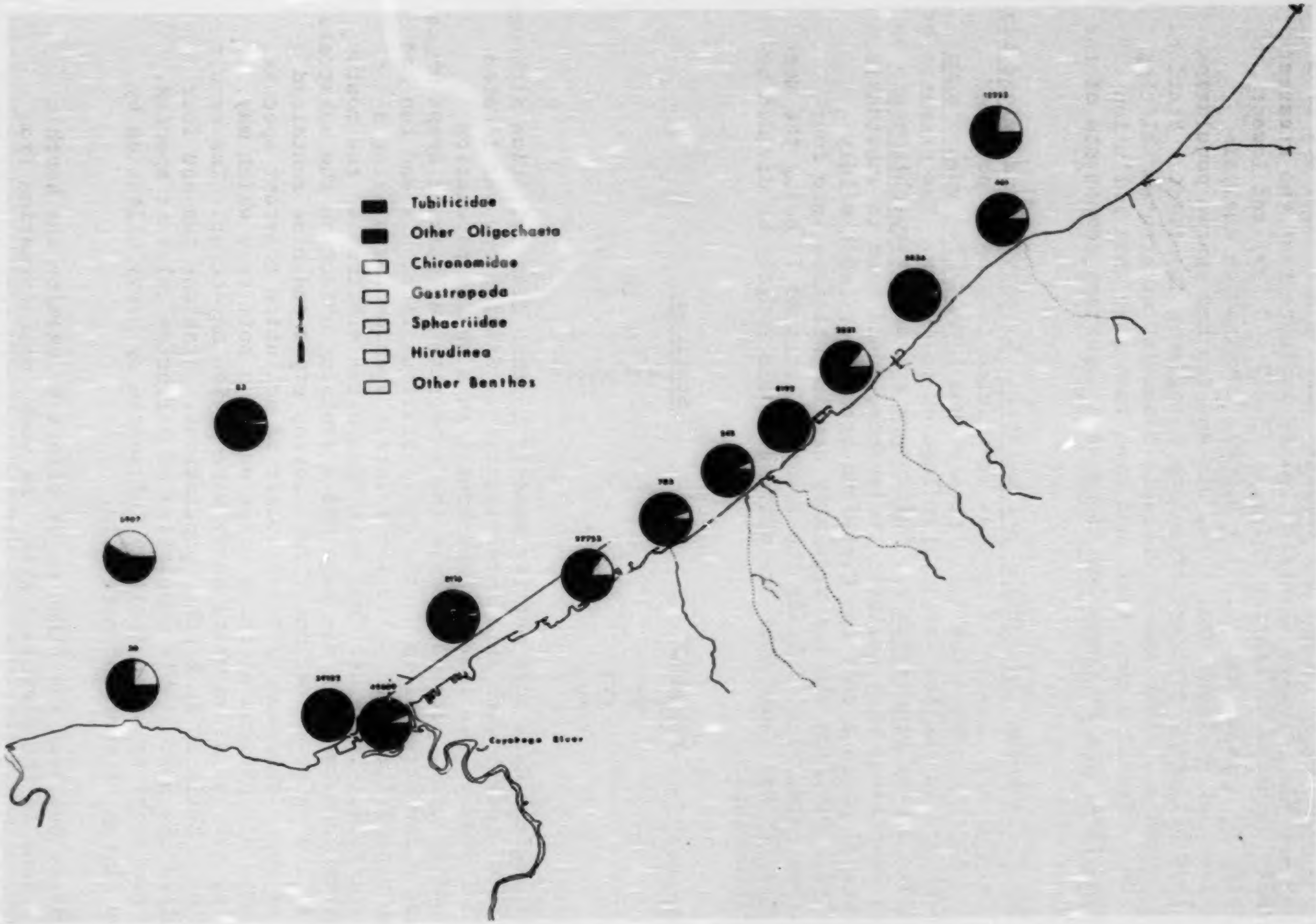

Tubificidae
Other Oligochaeta
Chironomidae
Gastropoda
Sphaeriidae
Hirudinea
Other Benthos
Cuyahoga River

Figure 29. Relative abundance of the major benthic groups at the fourteen regular sampling stations, represented by areas within the circles. The number above each circle is the mean density of tubificids per square meter (Rolan, 1973).

The largest variety of organisms (54 and 52 taxa) were taken from the stations four and two while the smallest variety (16 taxa) was from station twelve. Species diversity values indicate that the greatest diversity occurred at station thirteen (3.217 ± 0.039) and lowest diversity at station one (0.946 ± 0.608). Ordination analysis indicated that stations one, five, six and ten had sparse populations with less pollution tolerant organisms being more important. Stations three, seven and eight showed unstable community structures shifting with time. Stations two, four, and nine indicated that pollution tolerant organisms at these locations were important components of the fauna.

The tubificid worms *Limnodrilus* *hoffmeisteri*, *L*. *cervix*, and *Pelexcolix multisetosus* were listed as species restricted to grossly polluted areas. Another common tubificid present was *Limnodrilus* *udekemianus* which occurs in shallow water regardless of pollution. The presence of the midge larvae *Procladius* sp, *Chironomus* sp, and *Crytpochironomis* sp, genera associated with pollution tolerance, would seem to substantiate the general picture that the Cleveland area is at least mildly polluted. Dividing the ten regularly sampled stations into four pollution categories, I being the least polluted to IV being the most polluted, it was found that the stations could roughly be divided by ordination into:

Category	Stations
I	1
II	3, 6, 10
III	5, 7, 8, 9
IV	2, 4

The biological data does not fit exactly to this classification although it agrees closely with this interpretation. Station one was located furthest west of the stations and contained a sparse population tolerant species, perhaps because the substrate was current swept which did not allow material to settle out. Stations five, six and ten had sparse populations with pollution tolerant species not playing a dominant role. These stations were open water stations at the mouths of several creeks which may have had a sweeping effect on the substrate causing its shift. Stations three, seven, eight and nine contained species which contained a major number of pollution tolerant species. The substrate present at these sites was of a soft type which may build up even at sites where heavy wave action may occur. The result would be a build up in benthic populations. Stations two and four contained the most stable population of pollution tolerant species. These two stations are definitely influenced by heavy siltation by various types of sediment materials.

This study has been the first major effort to examine the benthic populations in the Cleveland area. As such, no information from previous work was available and data gathered in this project would seem insufficient. This report indicates how great is the lack of knowledge of benthic population in this area and demonstrates the need for a more comprehensive survey of the area. Preliminary data indicates that sections of the area are grossly polluted while several places are only moderately or slightly polluted. This, however, is only a result of isolated stations. Work should be done on clusters of stations rather than isolated stations and the time between samples decreased. Species diversity and ordination techniques are powerful tools, if sufficient amounts of specific data are available which should be used in any community analysis of the Cleveland lakeshore area. More information must be gathered about the interaction of various chemical-physical factors with the biota, particularly the influence or toxicity of the sediments to the biota which form the basis for the food web in this area of the lake.

The fish population study was accomplished by Dr. A. M. White of John Carroll University, and it is fully presented in Volume II. The fish populations were studied to establish a firm baseline, and to define the changes that affected the various species, their abundance, and distribution in the past and at present. Changes related to water quality and alterations of land use were documented from historical documents.

This study was the first exhaustive delineation of fish populations in the Cleveland region. Using a number of techniques, the investigators collected and examined 77,000 specimens of fish. The fishes were identified and catalogued in relation to abundance designating each group in these categories: Extremely abundant, abundant, common, uncommon and rare or commercially extirpated. All this data is presented in Volume II.

The study shows that the present fish fauna is very different from about a hundred and fifty years ago. The fish populations have changed from clean water forms (Muskellunge, Walleye, Lake Trout, Silver Chub, Burbot) to "rough" forms (Goldfish, Carp, Gizzardshad, Perch). The study concludes that stream spawning fish populations were drastically reduced by physical dams and latter by "chemical dams" from pollution preventing upstream migration. The changes in the fish populations were directly related to pollution loadings and alterations of the physical environment from human activities.

The study shows that fish populations in the study area are under stress, and shows the variability of the distribution of the stress. The critical areas are the lower seven miles of the Cuyahoga River, Edgewater area, and Cleveland Harbor. The study recommends immediate action. This study meagerly summarized here, because it is presented fully in Volume II, is possibly the most complete and significant accomplishment of the entire project.

White found that the three principal fish nursery zones in the study area were the lower mile of Rocky River and the adjacent shoreline, the Cleveland Breakwall System and the marinas, and the lower mile of Chagrin River and the adjacent Lake Erie shoreline. About 30 different species are reproducing in the Chagrin Zone, about 24 species in the Rocky River Zone, and about 12 species in the Cleveland Breakwall System. Subsequent more detailed investigations of smaller creeks have shown that fishes are reproducing at the mouths of these creeks and adjacent shorelines. This indicates that with the decrease of stress from water pollution control, a number of nearly extirpated fish species could repopulate the area.

Table 18A shows that a number of clean water species still can be found in the area such as Rainbow Trout, Northern Pike, Yellow Walleye, Largemouth Blackbass, etc. Although rare in numbers, these fishes could represent the necessary stock source for the restoration of fish population at the immediate Cleveland shoreline (White, 1973). Removal of pollutants by point source pollution control and selected dredging with supporting measures like artificial reefs are required for such restoration.

White concludes in a personal communication in 1974 that "in an area such as the Cleveland Harbor or Cuyahoga, where current attitude is that no fishes are present I feel that the restoration of fish populations would be a striking example of the clean up program in the City and would be of significance to the area, the State and the Nation". These comments are in concert with this entire report, and philosophically, also, in agreement with the basic restoration provision of the major federal water quality legislation, notably with those of the Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500).

Table 18A. SPECIES OF FISHES COLLECTED IN OR NEAR THE CLEVELAND HARBOR IN 1971-1974

(collections by White with specimens preserved in the
John Carroll University Museum)

---

* Longnose Gar
Alewife
Eastern Gizzardshad
* Rainbow Trout
Coho Salmon
Chinook Salmon
Rainbow Smelt
* Northern Pike
* Eastern Quillback Carpsucker
* Golden Redhorse
White Sucker
Carp
Goldfish
Goldenshiner
Common Emerald Shiner
Spottail Shiner
Bluntnose Minnow
* Channel Catfish
* Brown Bullhead
* Black Bullhead
* Stonecat Madtom
Troutperch
White Bass
White Crappie
* Black Crappie
* Warmouth Sunfish
* Largemouth Blackbass
Bluegill Sunfish
Pumpkinseed Sunfish
* Yellow Walleye
Freshwater Drum (Sheepshead)

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* Indicates those species that are only rarely collected.

SYNTHESIS AND EVALUATION

The synthesis of the data obtained from the individual investigations combined with available information from other studies presents a rough but viable description of the water quality in the near shore Lake Erie waters between Rocky River in the west and Chagrin River in the east. None of the investigations, except for the fish population study, established a firm and scientifically complete water quality baseline. The acquired data, however, is an important and vital departure line for intensive water quality monitoring and surveillance, water quality restoration programs, and water pollution abatement program effectiveness. There are four principal areas that must be considered as the core of the synthesis. These are:

1. Major factors in the history of the degradation of the water quality in the study area.
2. Present status and patterns of water quality in the study area.
3. Public health considerations as related to present water quality conditions.
4. Sociological aspects as related to environmental water quality conditions.

The project research on the history of water quality decline clearly indicates that there were definite successive impacts. These impacts were direct consequences of human activities. The initial impact resulted from the modification of the physical environment which was accompanied by the partial destruction of the flora of the region. This modification was characterized by denudation of land for agricultural uses, damming of streams for power, draining and filling of marshes. This produced siltation, destruction of spawning areas, and partial extirpation of stream spawning lake fishes.

The second major impact occurred in the second half of the 19th century. The growth of the population with industrialization produced excessive waste, which was discharged untreated into the waters. This produced excessive waste, which produced a profound stress on the aquatic system resulting in extirpation of fish life described in Volume II of this study.

The third major impact resulted since about the beginning of the 20th century and is still being exerted. This is a progressive, continuous pollution loading into the Cleveland area watershed. This continuous loading has produced toxicity from industrial wastes, enriched the waters from oligotrophic to early eutrophic, and has created bacterial contamination. Compounded by excessive siltation of streams from poor land use and floodplain management, this third impact has caused diminished availability of clean water for public water supply and recreational purposes. It has altered the fish fauna from clean water valuable food fishes to pollution tolerant low food desirability fishes.

The review of the history clearly indicates that the initial phase of water quality degradation in the study area consisted of physical impacts resulting from physical alteration of the environment. It, also, shows that the removal of pollution sources alone will not restore the water quality. This demonstrates the critical tie between land use (physical environment) and water quality.

The second principal area of consideration in the synthesis is the derivation of the various water quality zones as shown in Figure 12. Although these zones are based on estimated "pollutopleths," they are substantiated by benthic sediment chemical and biological data, chemical water measurements, phytoplankton and zooplankton studies, and bacterial analysis. Obviously the water patterns change due to storms and currents, but for most of the year these pollution "zones" are definable. This shows that the harbor area is a definite area of aquatic stress. Any additional stress will produce highly undesirable results such as complete fouling of the harbor. This means additional degradation on top of existing low water quality conditions. The dike construction and dredged material disposal by U. S. Army Corps of Engineers into the Cleveland Harbor should be diverted to other areas of the lake or preferably disposed in non-aquatic environments. Table 19 shows the chemical composition of the dredged material. Certain chemicals contained in these sediments are released to the aquatic environment depending on the anoxic or oxic conditions of the benthic environs (Table 19). All the public access recreational areas are in zones of either pollution or bacterial contamination, precluding these areas from use.

The pollution impact of the urban area is self-evident. Most of the highly degraded areas are related to proximity of point sources. Based on stream investigation data, all the streams are point sources. The overall degradation of the streams can be classed into these major areas:

chemical pollution (COD, toxicity)
sewage pollution (BOD, bacterial and viral)
debri and junk (domestic refuse, junked cars, etc.)
stream bank and floodplain (poor land use, bank erosion, sedimentation and siltation)

Streams in the study area are highly culverted, channelized, and destabilized. They are highly disrupted ecological corridors. However, with proper comprehensive environmental efforts, they can be restored, and become ecologically stabilizing factors in the urban environment.

Table 19. AVERAGE CONCENTRATIONS OF SEDIMENT CONSTITUENTS (mg/g)

Constituents	Cuyahoga River	Outer Harbor	Hopper Dredge Dump	Scow Dredge Dump	Central Lake Erie
Chlorine Demand	30	12	--	--	--
COD	240	95	106	178	41
BOD_5	15	5	6	10	1
Volatile Solids	125	65	67	140	63
Oil and Grease	35	8	10	15	0.4
Phosphorus	4	1.5	2.2	2.5	0.7
Nitrogen	5	1.6	1.6	2.7	1.9
Iron	110	45	90	150	35
Silica	550	720	655	535	--

Public health considerations are many, but the two central areas are viral and toxic contamination of water supply. Most of the effluents containing treated or partially treated sewage are disposed into Lake Erie. The effects on public water supply from viruses in the sewage can produce public health hazards, since Cleveland draws its water from the lake. The viruses that have been found in sewage are listed in Table 20. Although water pretreatment may be effective in destroying the viruses, at this time, that is unknown.

The other area of public health is toxic materials, especially as released by certain strains of blue-green algae. The known toxigenic algae are widely distributed geographically and belong to several taxonomic groups. In the Cleveland area, however, our major concern centers on several species of blue-green algae and one diatom species. The foregoing statement is based on presently available information. Those species which are known or heavily suspected of being toxigenic and which are known to occur within the Great Lakes area are:

Blue-green
- Anabaena flos-aquae
- Aphanizomenon flos-aquae
- Coelosphaerium kutzingianum
- Gloeotrichia echinulata
- Gloeotrichia pisum
- Microcystis aeruginosa
- Microcystis flos-aquae
- Nodularia spumigena
- Oscillatoria lacustris

Diatom
- Asterionella formosa

A complicating factor is that when intensive studies have been undertaken, it has been found that only certain strains of the species are toxigenic. At this time it is not possible to determine in advance which strains will be toxigenic and which will be harmless. The blue green algae toxins, when proper strains do occur are not released to the water until the cells die. In order to test the toxicity the cells must be lyophilized by either mechanical or chemical means. Thus in the water treatment process, if the cellular structure is destroyed before the cells are removed from the water any toxins present would be released in the water treatment process.

To date there has been no extensive work done on the possible presence of toxic algae in Lake Erie. The Cleveland Water Quality Laboratory (1972) did perform a few tests on gross samples collected during bloom of August, 1972. The test animals laboratory mice, exhibited convulsions, pallor and prostration when injected freeze-dried cells intra peritoneal. All but one of the mice recovered within 24 hours. The single mouse that died had been injected with a 340 mg/kg body

Table 20. VIRUSES POSSIBLY PRESENT IN SEWAGE AND RESULTING DISEASES

Virus	Diseases or Clinical Syndromes
Poliovirus	Paralysis, aseptic meningitis, undifferentiated febrile illness
Coxsackievirus Group A	Herpangina, aseptic mengingitis, paralysis, exanthem, "common cold", undifferentiated febrile illness
Coxsackievirus Group B	Pleurodynia, aseptic mengingitis, paralysis, meningoencephalitis, myocorditis, pericorditis, upper respiratory illness, pneumonia, undifferentiated febrile illness
Echovirus	Aseptic meningitis, paralysis, exanthem, respiratory disease, diarrhea
Adenovirus	Acute febrile pharyngitis, phanyngoconjunctival fever, acute respiratory disease, pneumonia
Reovirus	Respiratory illness, diarrhea
Infectious hepatitis virus	Jaundice

Table 21. PLANKTON ANALYSIS OF TAP WATER
3200 LITER SAMPLE TAKEN AUGUST 8, 1973

Organism	Number per liter	Organism	Number per liter
Anabaena	125	Naphtocytium	14
Aphanizomenon	48	Botryococcus	70
Ascillatoria	21	Pandorina	14
Gomphosphaeria	5	Chlorococcum	11
Dinobryan	3	Ooceptis	20
Nadularia	1	Mougoetia	3
Stourostrun	7	Tetraedon	1
Casmarium	1	Quadrigula	3
Pediastrum	45	Chlorella	3
Sphaerocystis	49	Crucigenia	2
Gloeocystis	33	Scenedesmus	2
Stephanodiscus	P[a]	Fragillaria	5
Tabellaria	P	Nematodes	P
Ceratium	P	Midgefly larva	P
Nitzschia	P	Rotifers	P
Sled shrimp	P		

[a] P denotes present but less than one per liter

weight dose and died within 24 hours. All the other mice received injections of 80 mg/kg body weight. Although the dose is considerably greater than the standard 40 to 60 milligram dose, it should be noted that the injected material contained not only Anabaena and Microcystis but also all types of algae present in the lake. Alldridge in 1973 estimated that no more than 10% of the phytoplankton biomass is blue-green algae, which means that the actual dose of blue-green algae should be no greater than 40 mg/kg body weight. Table 21 presents the results of a recent analysis of city tap water. The water was collected from a tap at the Water Quality Program, 3090 Broadway. The suspended material in the water was collected by passing 3200 liters of water through a Wisconsin style plankton bucket. The collected material was then washed from the bucket and concentrated into a Sedgewick-Rafter plankton counting cell, and the collected plankton enumerated. Since the method usually collects no more than 50% of the suspended particles for this type of water, the results are heavily weighed towards the low side. However, the results do present the fact that although the water is bacteriologically safe, it is not free from objectional and possibly injurious material. Anabaena sp, one of the major types implicated in algae poisoning, is one of the major constituents of the residential plankton in the municipal tap water.

The reference to the viral and toxic material possibilities in the public water supply should not be considered as scare tactics. No environmental quality and public health assessment and management framework can be considered sound if it does not consider all the possibilities.

The sociological aspects that must be considered in the synthesis are related to quality of life values. One of the major sources of aesthetic and cultural values in an urban area can be the natural environment within the area. If, however, the natural environment is degraded, this fact can act as a depressing mechanism on the society. In Cleveland area the degradation of the environment can be related to past public apathy. This past apathy toward the environment is difficult to envision in a sensitive community like Cleveland. In terms of public responsibility toward the aged, the destitute, the unfortunate, the ill, etc., the community is one of the more responsive cities in the nation. Its response in terms of positive programs, and financial support from private and public sectors, makes the Cleveland area a leader. But only in the last few years has environmental quality become of major concern. Cleveland has been flagellated and ridiculed on the news media for a "dead lake" in its backyard for over a decade. Part of the apathy could be related to Lake Erie shoreline accessibility to the public. Of about twenty two miles of the shoreline in the study area, only about four and a half miles are accessible to the public as park or private recreational areas. Since the accessible areas have contaminated water offshore, in an urban area this spells apathy -- no access, no involvement.

The general synthesis is the sum total of available inputs from this project and many other studies done previously and concurrently. The water quality conditions in the study area shown in Figure 12 were derived from all available data. The extent of each zone depicted on the map can change with currents, wind, season, and many other factors. However, the general conditions prevail as supported by biological and chemical evidence. Although, the "pollution zones" are in part a subjective interpretation, they are geographic-aerial designations of water quality conditions generally prevailing in the study area. From this map, priorities in restoration and water pollution control programs can be established. As part of the total synthesis several major points are evident.

The first major point is that popular designations of the death of Lake Erie off Cleveland shore are false. The pollution, however, is real, and the water is heavily degraded. Based on the available data, Cleveland Harbor is a zone of pronounced aquatic stress. The fish population study (White, 1973) shows that the Cleveland Harbor breakwall and around the Edgewater complex are primary fish feeding and spawning areas. This establishes a priority for these areas, demonstrating that future modification and present pollution of the Harbor must be severely reduced.

The second major point is that the Cleveland communities, city proper and suburban, are involved in positive programs of pollution abatement. The next few years will be critical in terms of completing the planned programs. Close to 300 million dollars of federal construction funds for water pollution abatement have been allocated to the Cleveland Regional Sewer District for these programs. Upon completion of the initial construction programs, a marked improvement in water quality may occur.

The third major point is that the Cleveland area aquatic environment can be and is being rehabilitated, and this rehabilitation will bring multiple economic and social benefits. One of the benefits may be the restoration of the fisheries in the Cleveland area. Dr. White, the principal investigator of the fish population study, estimates that the annual loss to the Cleveland area due to destruction of fisheries is over $8,000,000. He points out that with proper management approaches these fisheries can be restored.

The fourth major condition is that the use and abuse of the geologic environment (land use) is critically related to water quality, as shown by the history of the degradation. This means that steps other than removing point source pollution will also be required to restore the water quality of the area.

The fifth major condition is that restoration programs aiming at full rehabilitation of the Cleveland water quality, must set goals in water quality related to conditions existing prior to 1850. The total dissolved solids began to increase over a hundred years ago, as well as other pollution. Full rehabilitation may require much different approaches.

As a final point this project achieved some success. Although, a complete baseline was not fully established, valid scientific description of the water quality conditions in the study area was obtained. This project also demonstrated that cooperative efforts on a broad basis can be achieved between federal, local, and educational institutions.

SECTION VI

NEEDS

PRIORITIES

Based on the evaluation of this project and data from other reports, particularly from MASTER PLAN FOR POLLUTION ABATEMENT by Havens and Emerson of 1968, and LAKE ERIE REPORT by FWPCA in 1968, general and specific needs have been delineated for water pollution control and water quality management for the Cleveland area. The intensity of these needs dictate the priorities. The response to specific needs is presented in the recommendations of this report. There are three areas of need which require immediate response. These areas are in applied research, in demonstration projects, and in pollution control.

Applied research must continue at accelerated paces to define the ecological system of the region on an integrated basis. This should be accomplished through a comprehensive, interdisciplinary base, rather than task oriented individual investigations. The lack of tying together of physical environment factors, biological systems, and human activities may result in the assignment of artificial priorities and not produce desired water quality improvement.

Demonstration projects are fundamental in developing successful environmental rehabilitation techniques. A successful restoration or rehabilitation of a real environment system has a number of inherent benefits. For example, the restoration of a degraded watershed can bring benefits, one of them being that is can serve as a working environmental model for rehabilitation of other watersheds. Another benefit is the analytic cost-benefit capability that can be derived from the project. One of the most important benefits is in winning the confidence of the public and other parties by demonstrated and visible success. In this area the Cleveland community needs renewed faith in water quality programs to sustain its energies and committment to environmental improvement.

The importance in actually minimizing pollution cannot be overemphasized. This requires committment of technology, law and social values to the idea that environmental quality is part of the quality of life. The preservation and improvement of environmental quality can be achieved through the recognition that nature does not have an infinite capacity to absorb waste products from human activities. The dominant philosophy in relation to all activities must provide for recycling of energy and materials with minimum discharge to the environment. This can be accomplished through better engineering of new processes, improvement of old processes, more strict legal control, and overall reeducation of the community in relation to common environmental goals. The results that must be obtained in the Cleveland region in water pollution control are drastic reductions in pollution loadings.

This area is critical in view of the degraded water quality of the region. Pollution control must start at the local level consistent with national objectives, but in all aspects it must be a local effort and a distinct responsibility of the elected officials. Only through local committment can environmental quality efforts succeed in the long run. Local efforts must be encouraged, supported, and given freedom of action within a broad range of national and state objectives.

WATER QUALITY MANAGEMENT

One of the most critical factors that determines the success of an environmental quality program is the base on which the program is designed. The base must be comprehensive and interdisciplinary. The stress is on an interdisciplinary base to prevent the domination of traditional disciplines evolving narrow approaches resulting in partial solutions. Most environmental management approaches, even presently, are only in the multi-disciplinary stage of evolution which is inadequate. Multi-disciplinary is often confused with interdisciplinary. To distinguish between the two, the United States Environmental Protection Agency's definition in the 1973 publication, "The Quality of Life Concept," is appropriate:

> "Multi-disciplinary" refers merely to gathering the information of the disciplines. "Interdisciplinary" means proceeding from the basis of an integration of the knowledge at hand, avoiding temptation to subjugate other disciplines to support one's own specialty. (p. I-21)

The interface of water, land, biological systems, and human activities is characterized by subtle and complex relationships. To manage water quality in this interface requires an interdisciplinary systems approach framework. This framework is represented by the integrated Environmental Management of Water Quality "matrix" in Figure 30. The basic components of this "matrix" are Environment, Disruptions, Effects, (Human) Ecosystem, Engineering and Technology, and Enforcement. The integration and proper balance of these components results in effective water quality management and adequate supply. Each component and subcomponent are interdependent with all the components and subcomponents in the "matrix". Each component must be as interdisciplinary as the total framework.

Environment

Definition and knowledge of the environment is basic. The biologic systems, quantitative and qualitative assessment of surface and subsurface hydrology, climate, and meteorology must be understood and integrated. The water interface with geology, soils, topography, and geomorphology must be scientifically defined. Availability and extent of water resources must be described through accepted and scientifically valid procedures for sampling, testing, documenting,

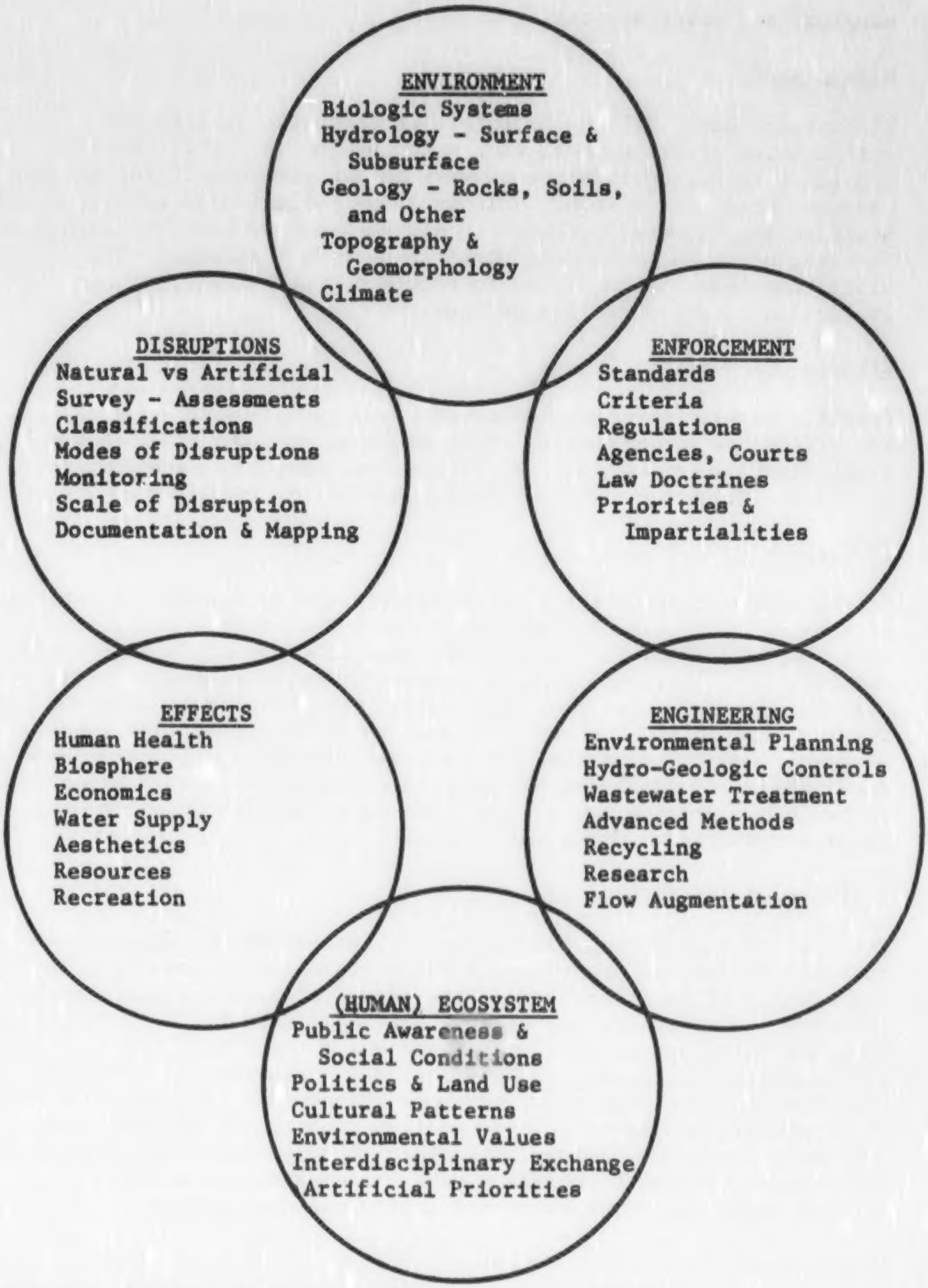
ENVIRONMENT
Biologic Systems
Hydrology - Surface & Subsurface
Geology - Rocks, Soils, and Other
Topography & Geomorphology
Climate
DISRUPTIONS
Natural vs Artificial
Survey - Assessments
Classifications
Modes of Disruptions
Monitoring
Scale of Disruption
Documentation & Mapping
ENFORCEMENT
Standards
Criteria
Regulations
Agencies, Courts
Law Doctrines
Priorities & Impartialities
EFFECTS
Human Health
Biosphere
Economics
Water Supply
Aesthetics
Resources
Recreation
ENGINEERING
Environmental Planning
Hydro-Geologic Controls
Wastewater Treatment
Advanced Methods
Recycling
Research
Flow Augmentation
(HUMAN) ECOSYSTEM
Public Awareness & Social Conditions
Politics & Land Use
Cultural Patterns
Environmental Values
Interdisciplinary Exchange
Artificial Priorities

Figure 30. Water quality management interrelationships (A. B. Garlauskas, 1971)

mapping, and other methods.

Disruptions

Disruptions deal with the factors that alter the quality and distribution of the natural waters of the region. This involves quantitative and qualitative surveys and assessments of the natural and man-generated disruptions. This includes pollution as well as other modification of water resources. All the sources must be classified in terms of scale, mode, and possible secondary effects. The disruptions must be monitored to obtain a systematic, periodic evaluation of water quality changes.

Effects

Possible effects from alteration of water quality must be evaluated. The effects on human health, the biosphere, economics, water supply, aesthetics, and resources must be qualitatively and quantitatively assessed. These assessments are fundamental in establishing priorities.

(Human) Ecosystem

This area encompasses the various factors that comprise the interactions of human society. Public awareness and socioeconomic conditions must be recognized as basic aspects that determine society's environmental committments. Politics, environmental values, cultural patterns and land use are variables that may control water quality conditions through indirect reallocation of water resources to degrading uses - waste disposal, power, mechanical cooling, and others. Utilization and integration of social and physical sciences and interdisciplinary exchange can provide new insight into water quality problems, and develop cooperative basis for action.

Engineering and Technology

The area of engineering and technology determines the physical controls that can be imposed on processes and waste disposal practices to control degradation of water quality. This area evaluates and integrates environmental planning approaches, available technological controls, land and water use methods, water and waste recycling, and environmental engineering. This includes evaluation of dredging, modification of stream flow, advanced methods of waste treatment and disposal, and areas of hydrogeologic controls. In this area, applied sciences of geology, limnology, hydrogeology, and hydrology work through a common interface with engineering, to arrive at optimum water quality control and improvement approaches.

Enforcement

The area of legal controls must have a sound scientific, engineering, and economic base for effective design and application. Standards,

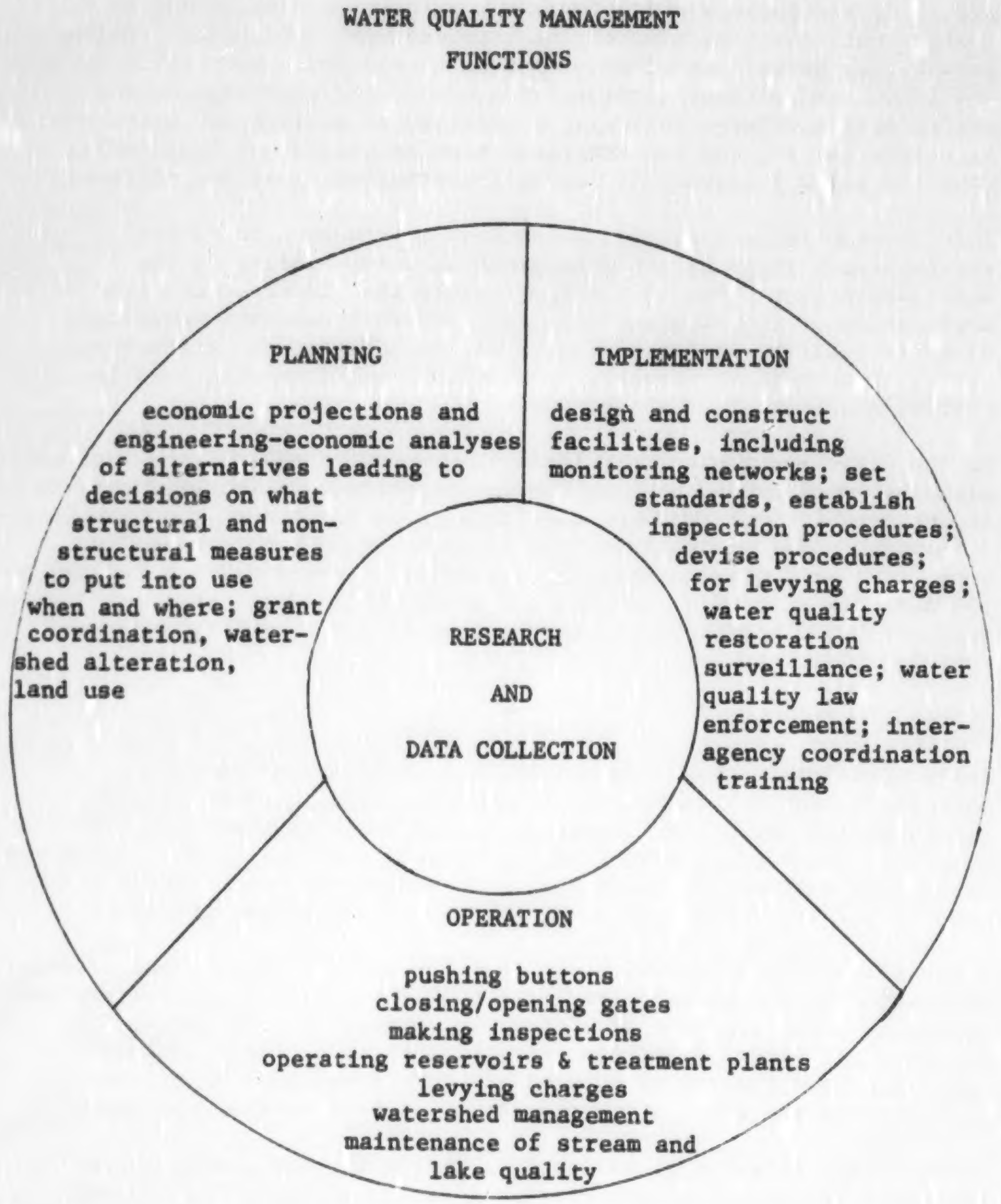
WATER QUALITY MANAGEMENT
FUNCTIONS
PLANNING
economic projections and engineering-economic analyses of alternatives leading to decisions on what structural and non-structural measures to put into use when and where; grant coordination, watershed alteration, land use
IMPLEMENTATION
design and construct facilities, including monitoring networks; set standards, establish inspection procedures; devise procedures; for levying charges; water quality restoration surveillance; water quality law enforcement; inter-agency coordination training
RESEARCH
AND
DATA COLLECTION
OPERATION
pushing buttons
closing/opening gates
making inspections
operating reservoirs & treatment plants
levying charges
watershed management
maintenance of stream and lake quality

Figure 31. Water quality management functions (Modified after Kneese, A. V., and B.T. Bower, 1968, Managing Water Quality: Economics, Technology, Institutions: Baltimore, The Johns Hopkins Press)

criteria, regulations and enforcement priorities must be set to conform with the realities of the environmental conditions. Engineering feasibility as well as effects must be considered. Many legal aspects are formulated without consideration or indepth knowledge of the environment and technological capabilities to achieve the standards. Agencies, courts, and law doctrines must be consistent in assuring that the legal framework is not self-contradicting or self-defeating.

This comprehensive base should serve as a framework in future environmental planning and management of water quality in the Cleveland region. One of the key factors that is fundamental in application of this framework is that the environmental management of water quality functions (Figure 31) be administered through one agency or authority. Separation of these functions will lead to partial achievement of objectives.

In the Cleveland region (the Three Rivers Watershed) all the research, planning, monitoring, and implementation pertaining to water quality of the region can be accomplished through an integrated approach in a regional water authority. This authority does not necessarily have to preempt or eliminate all the existing agencies, but it must be the managing authority, and develop goals, objectives, and implementation approaches. Segmentation of water quality management functions leads to ineffective programs.

SPECIFIC APPROACHES

Integrated broad scope programs in water quality and resources management tend to break down or become stymied, because specific methodologies are not sufficiently developed or sophisticated to implement the various objectives of these programs. In such cases the conceptual base of the management approach may be too advanced and complex for traditional "seat of the pants" management practices.

A specific methodology which can facilitate water quality and resources management at a regional level is the hierarchical multilevel systems approach. This approach employs various types of descriptive, mathematical, and experimental models to optimize the planning, operation, and control of natural and artificial factors of the quantitative and qualitative aspects of water resources systems.

Several significant regional studies in the Cleveland area employing the hierarchical multilevel systems approach on water quality and water resources management are being performed at Case Western Reserve University in the Systems Engineering Department. One study called Construction of Multilevel Systems Model for Regional Approach and Phosphorus Pollution Control conducted by Dr. M. D. Mesarovic is exploring the application of such approaches to deal with phosphorus pollution control in the Lake Erie Basin. The study is funded by the Rockefeller Foundation, and its first phase was completed in 1973.

The other studies are being conducted by Dr. Y. Y. Haimes and these are listed with the supporting agencies in Table 22.

These studies center around developing water resource management methodologies which have quantification and prediction capabilities. In dealing with large scale systems such as Lake Erie the numerous variables and their complex interrelationships can be defined and manipulated through the hierarchical multilevel systems approach. This approach is designed to deal with complex systems by decomposing the complex whole into independent parts, and analyzing these parts through subsystems modeling. Through this decomposition of the system to various levels of diminishing complexity, the subsystems can be analyzed (Figure 32). Then each lower level subsystem transmits its information to the next higher level as a reverse process of reassembling the complex system.

Multilevel decision management process of water quality and resources systems has several very important advantages. It allows for simplification of complex systems, which have societal, technological, and environmental variables operating, to a workable level. It incorporates feedback mechanisms, and it provides for the use of various types of problem solving methodologies such as linear programming, dynamic programming, etc. These methodologies can be employed to simulate the real system, and provide the necessary information to the various levels of decision in the hierarchical structure (Figure 33).

For the Cleveland area evaluation and management concepts like the hierarchical multilevel approach are of great importance in dealing with environmental problems in at least four areas. These are:

1. Regional water resources, primarily public water supply management.
2. Regional water quality management and pollution control of publicly owned wastewater treatment works, industrial discharges, and distributed point and area sources.
3. Water resources and water quality data collection and analysis systems.
4. Conjunctive use of water and land resources.

The first two areas in the Cleveland region are receiving over 1,000 million dollars in upgrading the water supply and water pollution control facilities in the next five years. With this huge investment of public and private funds, a systematic analysis of the effectiveness and cost-benefit of the improvements must be made. Also, at this time it is most advantageous to predict the economic and environmental impact of the compliance in the Cleveland region with the timetable provisions of the Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500).

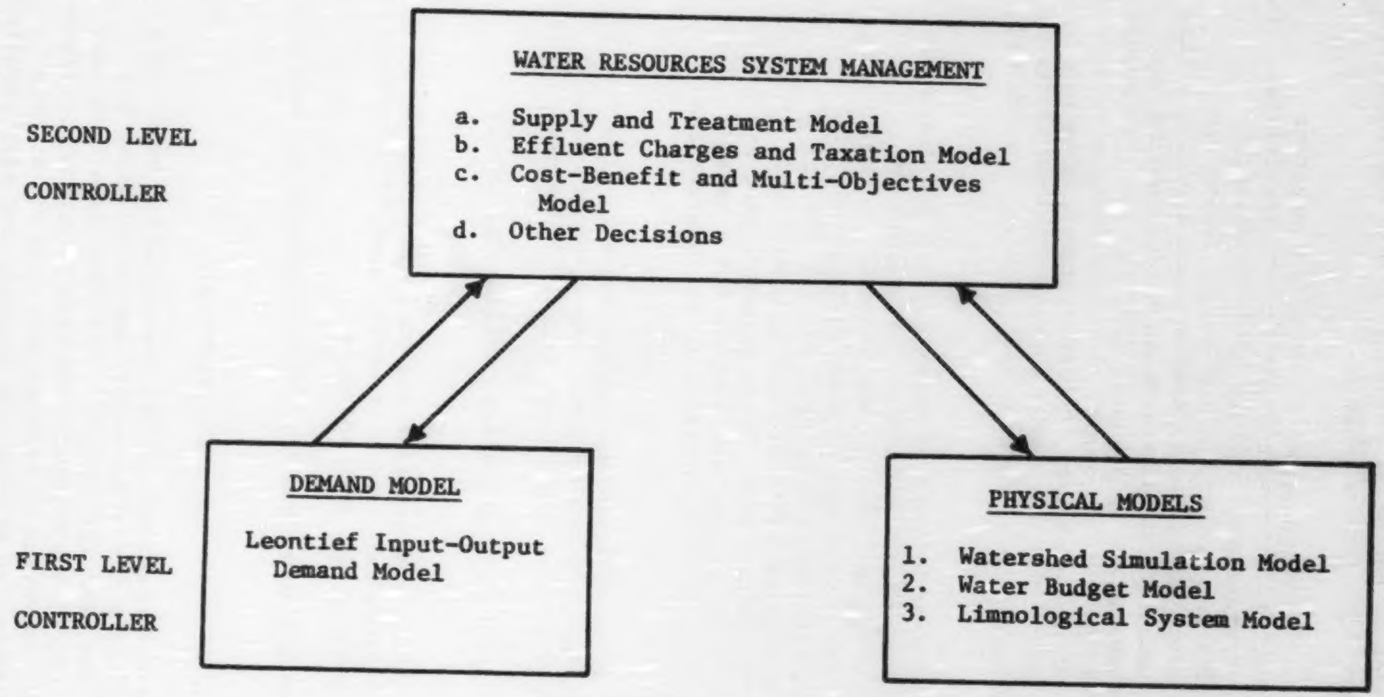
SECOND LEVEL
CONTROLLER
WATER RESOURCES SYSTEM MANAGEMENT
a. Supply and Treatment Model
b. Effluent Charges and Taxation Model
c. Cost-Benefit and Multi-Objectives Model
d. Other Decisions
FIRST LEVEL
CONTROLLER
DEMAND MODEL
Leontief Input-Output Demand Model
PHYSICAL MODELS
1. Watershed Simulation Model
2. Water Budget Model
3. Limnological System Model

Figure 32. Hierarchical multilevel systems decomposition (after Yacov Y. Haimes in 1973).

Table 22. REGIONAL WATER QUALITY MANAGEMENT PROGRAMS AT CASE WESTERN RESERVE UNIVERSITY

Program	Supporting Agency
Regional Water Quality Control and Management Program	U.S. Environmental Protection Agency
Multilevel Approach for Regional Water Resources Planning and Management	National Science Foundation
Integrated System Identification and Optimization for Conjunctive Use of Ground and Surface Water	U.S. Department of Interior, Office of Water Resources Research
Regional Approach to Phosphorus Pollution Control	Rockefeller Foundation
Analytical Framework for Design of Data Collection Systems That are Responsive to the Needs of Planning and Management of Water Resources and Land Related Systems	U.S. Department of Interior, Office of Water Resources Research

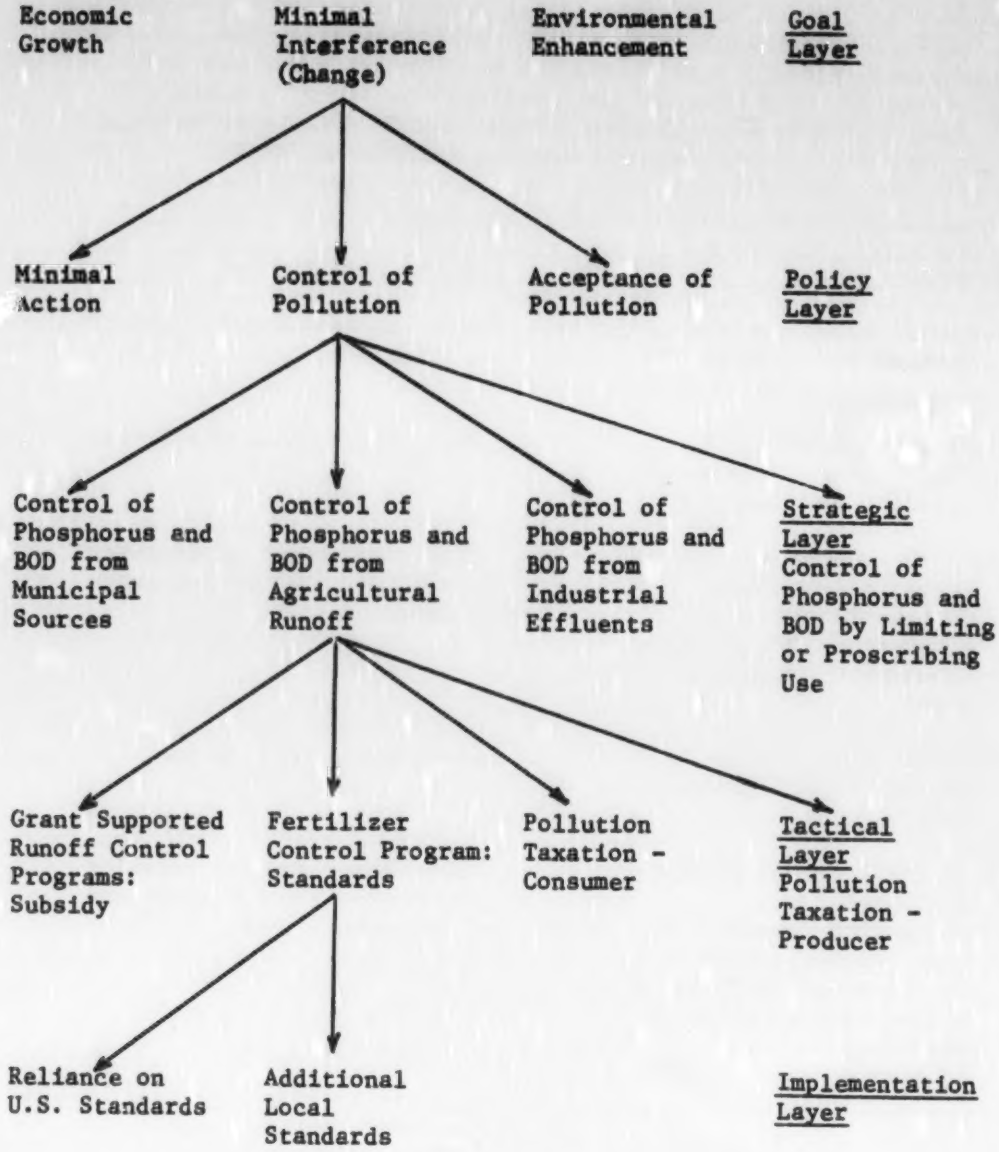
Economic Growth
Minimal Interference (Change)
Environmental Enhancement
Goal Layer
Minimal Action
Control of Pollution
Acceptance of Pollution
Policy Layer
Control of Phosphorus and BOD from Municipal Sources
Control of Phosphorus and BOD from Agricultural Runoff
Control of Phosphorus and BOD from Industrial Effluents
Strategic Layer
Control of Phosphorus and BOD by Limiting or Proscribing Use
Grant Supported Runoff Control Programs: Subsidy
Fertilizer Control Program: Standards
Pollution Taxation - Consumer
Tactical Layer
Pollution Taxation - Producer
Reliance on U.S. Standards
Additional Local Standards
Implementation Layer

Figure 33. An example of the hierarchical multilevel decision layer structure as applied to a regional phosphorus control program (after Richardson, J.M. Interactive Mode Decision Analysis. Case Western Reserve University, unpublished, 1973).

These factors can be evaluated most efficiently through simulation models closely resembling the real environmental systems of the Cleveland region. Such simulation would provide for better collection of data, for more relevant data collection, for proper and more comprehensive interpretation of data, and for better assessment of environmental impact resulting from alternate environmental policies. Most important it would justify or deny the present huge investments in water related projects, and it would provide a means for reassessing priorities for action.

As part of meeting some of the goals and objectives of the total program going into Phase II, several smaller scale restoration projects are underway. The initial planning and study phases of these projects have been covered by these reports:

1. Preliminary Report on Planning, Present Status, and Proposed Action of Big Creek - 1973.
2. Effluent Disinfection of the Cleveland Regional Sewer District's Sewage Treatment Plants: Performance, Present Status, and Needs - 1974
3. Cleveland's Industrial Water Pollution Abatement Programs - 1974
4. Preliminary Assessment For Restoration of Doan Brook and Shaker Lakes - 1974

These projects are integral parts of Phase II of the total Program following the general guidelines of section 108 of Public Law 92-500, the Federal Water Pollution Control Act Amendments of 1972.

The four projects characterize the action oriented Phase II, which has as its main general objective restoration of the Cleveland metropolitan area environmental quality concentrating on the urban streams and the near shore Lake Erie waters. The Phase II planning and initial action is being undertaken by the City of Cleveland Water Quality Program, an organizational group in the Division of Utilities Engineering of the Department of Public Utilities.

Several other large scope efforts are being undertaken by federal and state agencies. Those related to this program other than direct construction are:

U.S. Army Corps of Engineers
Wastewater Management Study - 1973
Cuyahoga River Restoration Study - 1973
Lake Erie Water Quality Study - 1974
Cleveland Harbor Study - 1974

Lake Erie Regional Transportation Authority
Cleveland Lake Erie Jetport Study - 1973-1974

National Commission on Water Quality
Proposed Great Lakes Study (concentrating on Lake Erie, Cuyahoga River, etc.) - 1974

Ohio Environmental Protection Agency
Implementation of Section 303 of P.L. 92-500 - 1973-1974 (including modeling of the middle and lower Cuyahoga River)

These efforts are developing fundamental interdisciplinary planning of water quality and water resources. They are characterized by comprehensive approaches encompassing conjunctive use of land, water, air and energy resources. These programs are responding to an overall need for better planning in dealing with complex environmental problems.

In evaluating all the past and present studies and programs, and reviewing the history of the degradation of the environmental water quality of the Cleveland metropolitan area, one basic need becomes evident. This need is in recognizing the proper priorities in the use of the available water resources. Lake Erie provides prime public water supply for over seven million people living around the basin. The Cleveland water system alone draws water supplies for 1.75 million people. This fact by itself establishes a top priority of use, and forces incompatible uses such as waste discharge to the lowest priority. Other uses that are compatible with public water supply like transportation, food supply - fishing, recreation, and power reinforce the incalculable value of the Lake.

The basis of using the Lake for waste discharges rests on the assumption that the waste assimilative capacity of natural waters is a resource and should be exploited. However, natural resource allocation is based on priorities, and in the case of Lake Erie the priorities are dictated by the higher use, that being public water supply. These two uses although not always completely incompatible, have become so in the Cleveland area, because the extent and nature of discharges have surpassed the assimilative capacity of Nature long time ago. This phenomena is clearly demonstrated by the history and present water quality of the area.

The economic benefits of allocating the Cleveland waters for waste discharge to decrease wastewater treatment costs are questionable, because the costs are passed on to increased cost of treating polluted water for public water supply, loss of recreation, fishing loss, and loss from overall degradation of the ecosystem. The phrase "there is no such thing as a free lunch" characterizes the argument. The federal goals of diminishing waste discharges to inconsequential levels as delineated in P.L. 92-500 are basic responses to prevent irreversible changes in the environment. Only when these goals are used as basis for all water quality and water resources planning and management in such urban areas as Cleveland, can Lake Erie remain a resource for the millions.

SECTION VII

GLOSSARY

Advanced Waste Water Treatment - Waste water treatment beyond the secondary or biological stage that includes removal of nutrients such as phosphorus and nitrogen and a high percentage of suspended solids. Advanced waste treatment known as tertiary treatment is the "polishing stage" of waste water treatment and produces a high quality effluent.

Algae Bloom - A logarithmic increase in abundance of a population of algae due to an ease in environmental restraints.

Aquatic Chemistry - The chemical study of natural waters.

Aquatic Ecology - The interrelationship between organisms and their environment in natural waters.

Benthos - Organisms attached or resting on the bottom of a stream, lake or ocean or living in the bottom sediments.

Biochemical Oxygen Demand (B.O.D.) - A measure of the amount of oxygen consumed in the biological processes that break down organic matter in water.

Biomass - The standing crop or total mass of living substance.

Buffering - The stabilization of pH with the use of an intermediate ionic species.

Cation - A positively charged ion.

Chemical Oxygen Demand (C.O.D.) - A measure of the amount of oxygen required to oxidize organic and oxidizable inorganic compounds in water.

Cladophora - A genus of filamentous green algae normally attached to substrate.

Combined Sewer - A sewerage system that carries both sanitary sewage and storm water runoff. During dry weather combined sewers carry all waste water to the treatment plant. During a storm only part of the flow is intercepted because of plant overloading; the remainder goes untreated to the receiving stream.

Dissolved Oxygen (D.O.) - The amount of dissolved oxygen, in parts per million by weight present in water, now generally expressed in milligrams per liter.

Eutrophication - The normally slow aging process by which a lake evolves into a bog or marsh and ultimately assumes a completely terrestrial state and disappears. During eutrophication the lake becomes enriched in nutritive compounds, especially nitrogen and phosphorus, so that algae and other microscopic plant life become extremely abundant. Eutrophication may be accelerated by human activities.

Fish Biology (Ichtiology) - The study of fishes.

Geochemistry - The study of the distribution and amounts of the chemical elements in minerals, ores, rocks, soils, water, and the atmosphere and the study of the circulation of the elements in nature on the basis of the properties of their atoms and ions.

Groundwater - That part of the subsurface water that is the zone of saturation, including underground streams.

Hydrodynamics - That aspect of hydromechanics which deals with forces that produce motion.

Hydrology - The science that deals with continental water (both liquid and solid), its properties, circulation, and distribution, on and under the Earth's surface and in the atmosphere, from the moment of its precipitation until it is returned to the atmosphere through evapotranspiration or is discharged into the ocean.

In Situ - In its original place.

Interceptor Sewers - Sewers used to collect the flows from main and trunk sewers and carry them to a central point for treatment and discharge. In a combined sewer system, where street runoff from rains is allowed to enter the system along with sewage, interceptor sewers allow some of the sewage to flow untreated directly into the stream to prevent the plant from being overloaded.

Ion Exchange - The reversible replacement of certain ions by others, without loss of crystal structure.

Leachate - Liquid that has percolated through solid waste or other mediums and has extracted dissolved or suspended materials from it.

Limnology - The scientific study of the physical, chemical, meteorological and especially the biological and ecological conditions and characteristics in pools, ponds, lakes, and by extension all inland waters.

M.G.D. - Millions of gallons per day, a term commonly used to express flow.

Microstraining - The removal of the fine particles by use of micro screens and filters.

Oligotrophic - A lake which has a low supply of nutrients and thus contains little organic matter. Such lakes are generally characterized by high dissolved oxygen and low productivity.

Pelagic - Open water.

pH - A measure of the acidity or alkalinity of a material, liquid or solid. pH is represented on a scale of 0 to 14 with 7 representing a neutral state, 0 representing the most acid and 14 the most alkaline.

Phytoplankton - Minute floating plants.

Point Source - A discrete location or origin of a specific discharge. It may emanate from a single origin or from a group of origins discharging to the receiving water at a common location.

Pollutant - A substance which when introduced into a body of water at a given concentration and/or amount impairs or renders unfit the water quality as related to its allocated use such as drinking water supply, recreation, etc. A substance that degrades natural water.

Primary Waste Water Treatment - The first stage in waste water treatment in which substantially all floating or settleable solids are mechanically removed by screening and sedimentation.

Sanitary Sewers - Sewers that carry only domestic or commercial sewage. Storm water runoff is carried in a separate system.

Secondary Waste Water Treatment - Waste water treatment beyond the primary stage in which bacteria consume the organic parts of the wastes. This biochemical action is accomplished by use of trickling filters or the activated sludge process. Effective secondary treatment removes virtually all floating and settleable solids and approximately 90% of both BOD_5 and suspended solids. Customarily, disinfection by chlorination is the final stage of the secondary treatment process.

Storm Sewer - A conduit that collects and transports rain and snow runoff back to the groundwater. In a separate sewerage system storm sewers are entirely separate from those carrying domestic and commercial waste.

Suspended Solids - Small particles of solid pollutants in sewage that contribute to turbidity and that resist separation by conventional means. The examination of suspended solids and the BOD test constitute the two main determinants for water quality performed at waste water treatment facilities.

Thermal Pollution - Degradation of water quality by the introduction of a heated effluent. Primarily a result of the discharge of cooling waters from industrial processes, particularly from electrical power generation. Even small deviation from normal water temperature can affect aquatic life.

Total Solids - The measurement of the suspended and dissolved solids.

Water Budget - An accounting of the inflow to, outflow from and storage in a hydrologic unit such as a drainage basin, aquifer, soil zone, lake or reservoir.

Water Pollution - The addition of sewage, industrial wastes or other harmful or objectionable material to water in concentrations or in sufficient quantities to result in measurable degradation of water quality.

Watershed - The region drained by, or contributing water to, a stream, lake, or other body of water.

Zooplankton - Minute animal organisms which float free in the water, independent of the shore and the bottom, moving passively with the current.

SECTION VIII

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